NEGOTIATING AN UNCERTAIN FUTURE

A Multi-Sited Study of Narratives of Kenyan
Agricultural Climate Change Adaptation

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I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Signature:……………………………………………………………………………..

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UNIVERSITY OF SUSSEX

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PhD in Research (Development Studies)

NEGOTIATING AN UNCERTAIN FUTURE: A MULTI-SITED STUDY OF NARRATIVES OF KENYAN AGRICULTURAL CLIMATE CHANGE ADAPTATION

SUMMARY

This research addresses the following question: 'In the context of climate change, how do different actors narrate the uncertain, ambiguous and risky future of maize agriculture, and what are the implications?' A multi-sited and institutional ethnography approach was adopted in order to look critically at how knowledge and narratives of future change in Kenyan maize agriculture are constructed by a variety of actors. The thesis describes: contested narratives of climate change and climate change impacts (through an analysis of the global climate impact modelling endeavour); contested narratives of change on smallholder farms (based on two case study sites in Kenya); contested narratives of pro-poor technological interventions (including the development of genetically modified drought tolerant maize); and contested narratives of technology regulation (with a focus on Kenyan biosafety policy). It is shown that narratives are contested in multiple sites and by a variety of actors and, although the resolution of these contestations often fall along familiar lines of power and elite capture, there are examples in which alternative perspectives find agency. This is the case not only in national policy-making arenas and the board-rooms of international development initiatives, but also in the fields and communities of smallholder farmers, the offices of national research centres, and the operations of civil society organisations. It is argued that, within these diverse settings, critical analysis of the constructed nature of knowledge is a necessary foundation on which to open up the negotiation of Kenya's agricultural future to multiple alternatives.

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Acronyms

AATF	African Agricultural Technology Foundation
ABNETA	Agricultural Biotechnology Network in Africa
ABSF	African Biotechnology Stakeholders Forum
ACTS	Africa Centre for Technology Studies
AGRA	Alliance for a Green Revolution for Africa
AML	Africa Model Law
AMS	Africa Maize Stress (Project)
AOGCMs	Atmosphere-Ocean General Circulation Models
APSIM	Agricultural Production Systems Simulator
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
ASB	Alternatives to Slash and Burn
ASDS	Agricultural Sector Development Strategy
ASRECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
BBC	British Broadcasting Corporation
BLS	Basic Linked System
BMGF	Bill and Melinda Gates Foundation
CAADP	Comprehensive Africa Agricultural Development Programme
CABI	Centre for Agriculture and Biosciences International
CAN	calcium ammonium nitrate
CBD	Convention on Biological Diversity
CCAFS	Climate Change, Agriculture and Food Security
CEBIB	Centre for Biotechnology and Bioinformatics
CERES	Crop Environment Resource Synthesis
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Centre for Tropical Agriculture
CIMMYT	The International Maize and Wheat Improvement Centre (Centro Internacional de Mejoramiento de Maíz y Trigo)
CMIP	Coupled Model Intercomparison Project
CNRM: CM3	Centre National de Recherches Météorologiques Climate Model Version 3
COMESA	Common Market for Eastern and Southern Africa
CSIRO: Mk3	Commonwealth Scientific and Industrial Research Organisation Mark 3 Climate Model
CSRP	Climate Science Research Partnership
DAP	Di-Ammonia Phosphate
DECC	Department of Energy and Climate Change (UK)
DEFRA	UK Department for Environment, Food, and Rural Affairs
DFID	Department for International Development (UK)
DNA	deoxyribonucleic acid
DSMW	Digital Soil Map of the World
DSSAT	Decision Support System for Agrotechnology Transfer
DTMA	Drought Tolerant Maize for Africa

EBP	evidence-based policy
EC	European Commission
EFSA	European Food Standards Authority
ENSO	El Nino Southern Oscillation
EPZA	Export Processing Zones Authority
EU	European Union
FAO	Food and Agriculture Organisation (UN Agency)
GAEZ	Global Agro-Ecological Zones
GCM	General Circulation Model
GE	genetically engineered
GFDL: CM2	Geophysical Fluid Dynamics Laboratory Coupled Model, version 2
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GLAM	General Large Area Model
GM	genetic modification/genetically modified
GM	genetically modified
GMO	genetically modified organism
GPG	global public good
HadCM3	Hadley Centre Coupled Model Version 3
HFP	Humanitarian Futures Programme
ICPAC	International Climate Prediction and Applications Centre
ICRAF	The World Agroforestry Centre (formally the International Centre for Research on Agroforestry)
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IGAD	Intergovernmental Authority on Development
IITA	International Institute for Tropical Agriculture
ILRI	International Livestock Research Institute
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IRMA	Insect Resistant Maize for Africa
IRRI	International Rice Research Institute
ISAAA	International Service for the Acquisition of Agri-Biotech Applications
ISPC	Independent Science and Partnership Council
ISRIC	International Soil Reference and Information Centre
JRC	Joint Research Centre
KARI	Kenya Agricultural Research Institute
KEBS	Kenya Bureau of Standards
KEGCO	Kenya GMO Concern Group
KEPHIS	Kenya Plant and Health Inspectorate Service
KES	Kenya Shilling
KMD	Kenya Meteorological Department
KOAN	Kenya Organic Agricultural Network
KSC	Kenya Seed Company
LULUCF	Land Use, Land Use Change, and Forestry

LUT	Land Utilisation Type
MAM	March April May
NBA	National Biosafety Authority
NCCAP	National Climate Change Action Plan
NCCRS	National Climate Change Response Strategy
NCST	National Council for Science and Technology
NEMA	National Environment Management Authority
NEPAD	New Partnership for Africa's Development
NGO	Non-Governmental Orgnaisation
NRC	National Research Council
NRCS	National Resource Conservation Service
OFAB	Open Forum on Agricultural Biotechnology
PBS	Programme for Biosafety Systems
PLC	Public Limited Company
PUS	Public Understanding of Science
QTL	Quantitative Trait Loci
RABESA	Regional Approach to Biotechnology and Biosafety Policy in Eastern and Southern Africa
RCP	Representative Concentration Pathway
RNA	ribonucleic acid
RP	Research Programme
SOTER	soil and terrain
SPS	Sanitary-Phystosanitary
SRES	Special Report on Emissions Scenarios
SSA	Sub-Saharan Africa
SST	Sea Surface Temperature
STAK	Seed Traders Association of Kenya
TSBF	Tropical Soil Biology and Fertility
UN	United Nations
UN/ISDR	United Nations Office for Disaster Risk Reduction
UNEP/GEF	United Nations Environment Programme/Global Environment Facility
USAID	US Agency for International Development
USD	US Dollar
WEMA	Water Efficient Maize for Africa
WMO	World Meteorological Organization
WTO	World Trade Organization

Abstract

This research asks: **'How do different actors narrate the uncertain future of maize agriculture, how can those differences be explained and what are the implications of these differences for the challenges of climate change adaptation in Kenyan smallholder farming?'** Through the adoption of a multi-sited approach and using ethnographic and participatory research methods, as well as an analytical framework based around a schema of incomplete knowledge (Stirling, 1999a), this research unpacks a variety of narratives of change in a variety of locations and social and institutional contexts – narratives from actors within and beyond Kenya; from scientific communities and multi-national corporations; and from smallholder farmers – exposing incompleteness in their underlying knowledge bases and identifying opportunities and challenges for social learning and deliberative governance.

The four case studies of the research look at (1) the contested science of climate change and climate change impacts, through an analysis of the global climate impact modelling endeavour; (2) contested narratives of change within farming communities, based on two case study sites in Kenya; (3) contested narratives of pro-poor technological intervention, including the development of genetically modified drought tolerant maize; and (4) contested narratives of technology regulation, with a focus on Kenyan biosafety policy.

This thesis reveals the way in which contexts, incomplete knowledge, and interactions with others, shape different narratives of change; from the 'complexity logic' of climate-crop modelling, through the 'internalisation of knowledge' amongst smallholder farmers, and the impact-at-scale and business-minded priorities of the Water Efficient Maize for Africa project, to the polarised politics of biosafety regulation. It is shown that narratives are contested in multiple sites and by a variety of actors and, although the resolution of these contestations often fall along familiar lines of power and elite capture, there are also examples in which alternative perspectives find agency. This is the case not only in national policy-making arenas and the board-rooms of international development initiatives, but also in the fields and communities of smallholder farmers, the offices of national research centres, and the operations of civil society organisations.

It is argued that, within these diverse settings, critical analysis of the constructed nature of knowledge is a necessary foundation on which to open up the negotiation of Kenya's agricultural future to multiple alternatives.

Chapter One: Introduction

Given the diversity of 'rural worlds' and the importance of history and context on agricultural change, a variety of possible future pathways for agri-food systems open up.... Different possibilities exist for different people in different places, requiring a highly located, context-specific assessment… Exploring future scenarios in different settings, across different stakeholder groups, represents an important challenge – both methodologically and practically – but needs to be at the heart of any analysis. For only with such an open and reflexive process can alternative pathways towards sustainability be both envisaged and realised.

(Thompson et al., 2007: 50-51)

The Research Question

Across sub-Saharan Africa (SSA), particularly in response to the threat of climatic change, 'pro-poor' and 'climate-smart' technologies are increasingly seen as the means to a green revolution and a resilient future agriculture. However, whilst apparently addressing the linked social risks of climatic change, low yields, and food insecurity, such technological futures are not risk-free themselves. Contrary to the convincingly simple problem-solution narratives that often support technology-driven interventions, the complex, context-dependent, and multifaceted challenges of agricultural adaptation are subject to multiple assumptions, values and constructions of risk (Stirling et al., 1999).

In order to offer insight into the uncertainties of, and multiple perspectives on, agricultural adaptation and contribute to the establishment of a basis from which to achieve a deliberative governance of agricultural change, this research asks:

How do different actors narrate the uncertain future of maize agriculture, how can those differences be explained and what are the implications of these differences for the challenges of climate change adaptation in Kenyan smallholder farming?

The context for this research is Kenya, where rural livelihoods and national food production predominantly depend on small-scale rain-fed agriculture[1]; where agricultural development is central to national climate change adaptation strategies[2]; and where advanced crop breeding,

[1] The Kenyan Agricultural Sector Development Strategy (2010-2020) states that 75 per cent of total national agricultural output comes from small-scale production, and that these farm systems are mainly rain-fed (p10-11)
[2] E.g. the National Climate Change Response Strategy (NCCRS) and subsequent National Climate Change Action Plan (NCCAP) for 2013-2017

including through the use of genetic modification, such as in the Water Efficient Maize for Africa (WEMA) initiative, is being invested in by international donors and public sector research groups.

Major breeding programmes, such as the 'Drought Tolerant Maize for Africa' (DTMA) and WEMA initiatives, represent significant attempts to build climate change resilience in smallholder farming by lowering the water requirement thresholds of eastern and southern Africa's dominant staple crop. Within the outputs and reports of both initiatives a dominant narrative of agricultural change can be identified in which the problem of drought is illustrated through a number of related social risks (food insecurity, crop failure, poverty) that are understood as being particularly acute for the smallholder, and a need for a 'pro-poor' technological solution to a growing vulnerability to climate threats. Within these narratives, however, are a number of assumptions about trajectories of change and the relative risks and benefits of technologies.

Future climatic and agro-ecological changes for Africa are uncertain and associated with high degrees of spatial and temporal variability and this change is differently simulated within divergent climate-crop models and in controlled crop breeding stations. Furthermore, uncertainty emerges in local contexts, not just in response to climatic systems, but to linked social, economic, and political systems and often with implications for the appropriateness and adoption of technologies. In response to the social, economic, political and climatic uncertainties that emerge at local scales, a multitude of perspectives on technological risks and benefits, and a variety of contested narratives of change, emerge.

In this thesis, it is argued that effective adaptation to an uncertain and risky future depends on social learning and the integration and negotiation of alternative narratives within the diverse settings in which agricultural change is governed; not only in national policy-making arenas and the board-rooms of international development initiatives, but also in the fields and communities of smallholder farmers, the offices of national research centres, and the operations of civil society organisations.

By taking a multi-sited approach and adopting ethnographic and participatory methods, this research aims to unpack a variety of narratives of change in a variety of locations and social and institutional contexts; exposing incompleteness in their underlying knowledge bases and identifying opportunities and challenges for social learning and deliberative governance. The following section sketches out the broad design of the research and the rationale behind this design.

The Research Design

The research is designed to address the research question through a number of case studies, not necessarily to capture the entirety of narratives that exist in relation to Kenyan smallholder maize farming, but rather to represent diversity. The four case studies of the research progressively narrow in focus from (1) contestation over the mechanics of climatic change and its impacts; through (2) contested narratives of change in smallholder farming systems, and (3) contested narratives of pro-poor technological interventions within these systems; to (4) contested narratives around the regulation of these technologies. An initial study of climate-crop modelling offers an insight into the ways in which climate change and its impacts, with a particular focus on maize yield impacts in East Africa, are broadly defined and understood within a global academic community. From here the focus narrows to smallholder maize farming in particular and attempts to engage with climate change impacts and adaptations as experienced and defined by smallholders themselves. A study of the DTMA and WEMA projects, then, represents a focus on a specific technological narrative of adaptation for smallholders. Finally a study of Kenyan biosafety regulation focuses specifically on how a particular element of this technological narrative of change is contested and governed.

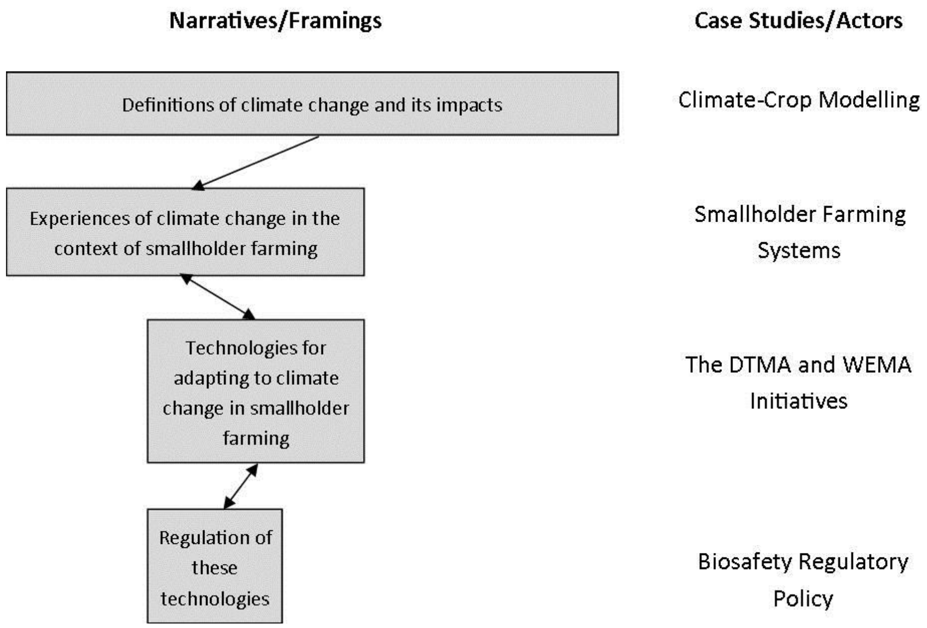

Figure 1: Schematic diagram showing the relationship between the four case studies of the research and associated narratives of future maize agriculture

Whilst there is a particular direction to the sequence of the thesis, beginning with an macro focus on global modelling and following interconnections between narratives and framings down to a micro-level focus on a particular sector of national policy, there are important two-way interactions between consecutive case studies. This is particularly evident in the way that regulation shapes technology development, and technologies become part of smallholders' experiences of climatic change. These interconnections will be highlighted throughout the thesis.

In each case study of the research, participatory and ethnographic research techniques – inclusive of assumption mapping; institutional ethnography; participatory scenarios; and narrative analysis (described in Chapter Four) – are applied and the following common set of sub-questions are addressed:

- Through what social interactions and within what social, cultural, economic, historical, institutional, and political contexts do stakeholders construct narratives about the future of agriculture?
- What evidence, experiences, assumptions, values, and methodological choices underpin these narratives?
- How are these narratives communicated to, and supported or closed down by others?

Each of the four case studies will be presented as an empirical chapter within this thesis, with the presented findings of the research organised around these three broad questions of context; the completeness of knowledge; and interactions between actors and narratives. A synthesis of the explanations of difference between these narratives and their implications, a key aspect of the central research question, will be addressed within a discussion chapter that looks more laterally across these four elements of the research.

Overview of the Thesis Structure and Arguments

A brief outline of each of the thesis chapters is provided here in order to give an overview of the structure and arguments of the thesis.

Chapter Two provides a detailed background to, and contextualisation of, the research. The chapter presents climate and crop yield change projections and describes the protocols, politics and operations of the Consultative Group on International Agricultural Research (CGIAR), the history of crop breeding, the state of national smallholder maize farming, the institutional arrangement of the DTMA and WEMA projects, and the historical and international context of biosafety policy. It essentially acts as a reference point for the later empirical chapters and begins to reveal a picture of a multi-sited yet interconnected set of contexts and actors that have a stake in the future of smallholder maize farming.

Chapter Three outlines the conceptual framework, which underpins the research. The framework is built on the traditions of social constructivist theories of knowledge and more contemporary realist approaches within the field. It sets out a review of this literature with a particular emphasis on theories of incomplete knowledge and the construction of risk. Andy Stirling's (1999) schema of incomplete knowledge, which draws distinctions between risk, uncertainty, ambiguity and ignorance, is advanced as an analytical tool for deconstructing knowledge claims and the nature of their contestation. The chapter goes on to set out a conceptual framework for considering the politics of incomplete knowledge; it discusses theories about the roles of power, persuasion and social learning in determining this politics; and it critically considers the concept of deliberative governance as a system of bridging knowledge gaps and facilitating a more collaborative approach to adaptation planning.

Chapter Four describes and justifies the methodological approach taken in the research and provides details of research locations, methods employed and data collected – essentially telling the story of a twelve month period of data collection that began at the UK Meteorological Office in Exeter and involved periods of time spent based at the World Agroforestry Centre in Nairobi and in rural villages in Central and Western Kenya. It explains the value, limitations, and potential insights, of applying the methodological principles of this research – multiple sites, participation, and ethnography – and how they complement, and can be used in connection with, the conceptual framework described in the previous chapter.

Chapter Five is the first of the empirical chapters and it focuses on narratives that are constructed within climate-crop models. As in all of the empirical chapters there are three themes in the presentation of the information. The first is a description of the institutional, social, and political context in which knowledge is generated; the second is a description of the incomplete nature of that knowledge (with a focus on areas of uncertainty, ignorance, and ambiguity); and the third is a description of the communication of knowledges and the interactions between narratives and multiple actors within and beyond these settings. In this chapter it is argued that there is a cultural convention within the modelling community of closing down incomplete knowledge to risk, addressing uncertainty by creating inter-model comparison databases and often taking the average of a set of models to represent 'most likely' change. This approach stems from what is labelled a 'complexity logic' and is the idea that the agro-climate system is so complex that models are limited by their simplicity and so either by combining a lot of models, or by seeking to add more parameters and higher resolutions to existing models they gradually close in on reality. This 'complexity logic' is something that legitimises expert ownership over knowledge. However, it is argued that this complexity logic is also being countered by an emerging convention, within the same community, that recognises that there are limits to the justifiability of seeking ever greater complexity. It identifies the emergence of simpler, non-predictive, and participatory modelling approaches and a recognition that models should be designed to contribute towards particular policy questions. This chapter is essentially about revealing the incomplete nature and ownership of the knowledge through which these projections of future change are produced, and challenging the conventions of this knowledge and its ownership.

Chapter Six presents narratives from smallholder farming communities in two maize growing districts of very different agro-ecological conditions and climate change projections – the predominantly semi-arid district of Makueni (in Central Province) and the moist 'transitional' environment of Nandi/Nyando (in Western Province). By presenting the stories of maize farmers collected through interviews and participant observations as well as the outputs of future scenarios workshops in which these farmers participated, the chapter shows that in response to uncertainty, rather than being dependent on external advice and information, farmers often depend on their own experimentations, indicators and experiences to make judgements about opportunities and risk. Projecting from these contemporary perspectives, and the histories of experience on which they are based, into the future, the scenario workshops revealed farmers' preferences for incremental, reversible and low-input cost changes - changes that they could trial for themselves before adopting whole scale – such as changes to land preparation and planting dates. The chapter also challenges some of the assumptions about adoption and decision-making that underpin the DTMA and WEMA narratives, the subject of the next chapter.

Chapter Seven then focuses on the WEMA and DTMA projects and presents an institutional ethnography that covered a number of the sites and partners through which these projects are advanced. It focuses particularly on the way in which the narrative of a universal technological solution, and the particular styles of science and evidence that underpin and legitimise this narrative, are shaped by the particular institutional setting of these projects – and within WEMA in particular, how it is shaped by the influence and priorities of its private sector partners. In the chapter it is argued that in adhering to the business-mindedness, state-of-the-art, and impact-at-scale priorities of Monsanto and of the Gates Foundation, who are arguably the main protagonists of the 'Green Revolution for Africa' discourse, WEMA science is geared towards the generation of particular sorts of evidence. As examples, crop breeding within the International Maize and Wheat Improvement Centre (CIMMYT – an institute of the CGIAR) has shifted to a focus on optimal rather than appropriate technology development; crop trials take place in 'mega-environments' that essentially compromise their ability to focus on local social, cultural, economic and political geographies; and socio economic impact assessments focus on identifying the barriers to technology dissemination rather than identifying farmer needs and preferences. The chapter suggests that CIMMYT and the broader CGIAR find themselves in a conflicted relationship with the private sector and in entering into public-private partnerships they often have to compromise on their mandate of providing global public goods, such that within WEMA, this provision is limited to a Monsanto-defined good (a transgenic maize variety) and a Monsanto-defined global public (a homogenous market that is not otherwise reached by Monsanto products). This chapter then broadly demonstrates the ways that apparently science-based narratives are shaped by institutional and political priorities, and highlights some of the ways in which they contrast with those of smallholder farmers (from the previous chapter).

Chapter Eight is the final empirical chapter and it looks at the regulation of genetically modified organisms (GMOs) in Kenya as particular policy sector within which technologies, such as WEMA, are governed and in which narratives of agricultural adaptation are contested. The chapter shows how, from a pro-GM perspective, which is characteristic of the narratives of the WEMA project's regulatory team, biosafety debate is often characterised as a science-based approach versus a value-based approach to regulation, as though the safety of GMOs has been unequivocally and objectively proven, and so taking a precautionary stance is somehow unscientific. In the case of the Biosafety Act, this discourse was fairly well sustained, and it resulted in an Act that was drafted by experts and largely unchanged across a four year period of very weak 'public consultation'. Obligations for considering the socio-economic impacts of the technology, for example, were lobbied for by civil society organisations, but were largely kept out of the Act. But, in contrast, the chapter shows that the more recent labelling regulations and the recent ban on the importation of GMO foods have really challenged the expert monopolisation of risk assessment and have actually been much more oriented towards the implementation of precautionary measures. This has implications for the viability and appropriateness of agricultural technologies, such as those of WEMA, and these implications are drawn out in the chapter.

Chapter Nine provides a discussion that particularly focuses on synthesizing the explanation of difference between narratives and addressing the implications end of the central research question. It outlines the prospects for and the challenges of achieving deliberative governance of agricultural change within the various settings of this research and it considers the role of power and social learning in shaping the governance of agricultural adaptation. It argues that good governance will depend on the integration of multiple narratives and opportunities for their collective negotiation, but identifies a number of the barriers to this kind of governance that emerged from the case studies. The chapter concludes with suggestions for overcoming these barriers and identifies a role to be played by particular actors and organisations as knowledge brokers. Reflecting on the approach taken to the research, it is argued that critical reflection on the nature of incomplete knowledge will be essential for opening up space for the negotiation of narratives.

Chapter Two: Background

Climate Change, International Agricultural Research and GMOs

Climate adaptation in Kenyan smallholder maize agriculture represents an important case for study for a number of reasons. As it is across much of eastern and southern Africa, maize is Kenyan's dominant staple crop and there is significant dietary and livelihoods dependence on maize particularly for subsistence producers and smallholder farmers[3]. The sensitivity of the maize plant to low water availability, coupled with increasingly unpredictable and extreme rainfall patterns, means that Kenyan smallholders are particularly vulnerable to climate change risk, and this vulnerability is recognised in national climate change adaptation and agricultural development strategies[4], as well as in the priorities of international donors and research efforts. In response, the introduction and regulation of new technologies such as genetically modified crops are subject to contested and contemporary policy debates across sub-Saharan Africa, with many countries looking to Kenya – as one of the most advanced African countries both in terms of technology development and regulatory infrastructure – as a test case for the technology.

Growing global interest in climate change and food security; new commitments to investment in the agricultural sector; and the emergence of new actors and new technologies within this expanding policy and research sector, mean that it is a particularly timely moment to look critically at which, and whose, narratives are being advanced, and why. This chapter gives context to the research through a description of some of the broader policy debates, agro-climatic changes, and international development agendas that the research case studies represent analytical windows into.

Climate Change and Maize Agriculture in Kenya

Despite an apparent incompatibility between the agro-climatic sensitivity of maize and the propensity for extremes in the ecological and climatic conditions across Kenya, and indeed across the African continent, maize has outlived many political, social, economic and environmental changes to remain as the most grown and consumed cereal crop nationwide[5]. Today it is grown on rain-fed agricultural land throughout Kenya, with an estimated 75% of national production coming from 3.5 million small-scale maize farmers (EPZA, 2005) that, often

[3] The World Bank's Rural Strategy defines smallholder farmers as 'those with a low asset base, operating less than 2 hectares of cropland' (World Bank 2003)

[4] e.g. the Kenyan 'Agricultural Sector Development Strategy 2010-2020' and the 'National Climate Change Action Plan 2013-2017'

[5] In 2010 Kenya produced 3.4 million tonnes of maize and the national consumption is estimated at approximately 3.6 million tonnes (based on FAO Stat data)

simultaneously, operate within subsistence and market systems (Omiti et al., 2009, Alene et al., 2008, Barrett, 2008).

The greatest concentration of maize production is in the Rift Valley, western and central regions, with some production in south-eastern coastal regions[6]. As such, production takes place in a range of agro-climatic conditions of varying compatibility with the, relatively specific, water requirements of maize[7]. Brooks et al. (2009: 2) explain that 'as the primary staple crop and a fundamental part of people's livelihood systems, maize is culturally and politically important'. For many Kenyans, *ugali* (a thick porridge made from maize flour) is the fundamental (and in some cases sole) component of people's diets and, particularly in rural Kenya, the most important social interactions, those through which local politics and knowledge exchanges take place, inevitably involve the sharing of ugali (Oniang'O and Komokoti, 1999, Osseo-Asare, 2005). Despite being Kenya's primary agricultural production commodity, the high demand that results from dietary dependence, means that Kenya is forced to import and/or rely on external aid to meet the maize supply-demand shortfall[8].

One particular aspect of maize's fragility is its sensitivity to low water availability, particularly during flowering[9]. In any given year, low rainfall and high temperatures have the potential to be the major constraints on realised yields in rain-fed systems, and particularly in dry agro-ecological zones (see Figure 9 map), low water availability is likely to be the main constraint in most years (Amissah-Arthur et al., 2002, Thornton et al., 2009, Hansen and Indeje, 2004). The result, despite the fact that the majority of production takes place in moist agro-ecological zones, and bearing in mind that annual rainfall patterns in Kenya are regularly composed of a highly geographically variable rainfall record, is that there is a correlation between national average rainfall and maize yields as shown in Figure 2, which displays rainfall data and maize yields over the period 1987-2000.

[6] According to data collected by CIMMYT as part of the 2001 Kenya maize growers survey (data available at: http://apps.cimmyt.org/agricdb/default.aspx)
[7] FAO crop water information (http://www.fao.org/nr/water/cropinfo_maize.html)
[8] FAOStat data on Kenya maize import and export data shows that between 1992 and 2008 (inclusive), Kenya has been net importer of maize in 15 of the 17 years (http://faostat.fao.org/site/616/DesktopDefault.aspx?PageID=616#ancor)
[9] Personal communication, CIMMYT (March 2012), triangulated through CERES-maize phenology literature [JONES, A. C., KINIRY, J. & DYKE, P. 1986. *CERES-Maize: a simulation model of maize growth and development,* College Station, Texas A&M University Press.] and FAO Crop Water Information (http://www.fao.org/nr/water/cropinfo_maize.html)

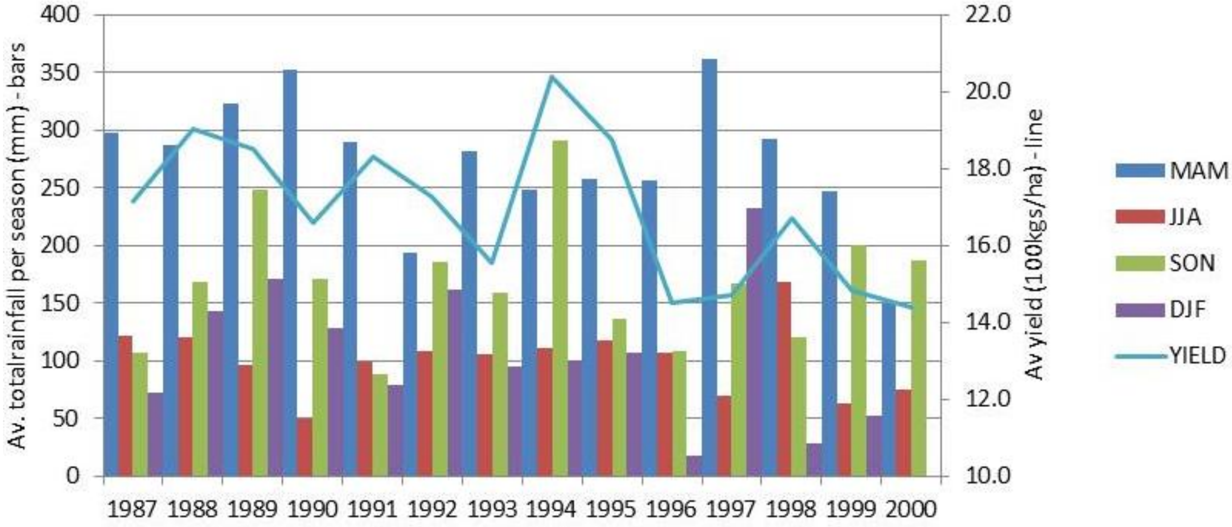

Figure 2 Graph showing Kenya's total rainfall per season (averaged over area) (mm) and average annual maize yield for the years 1987 to 2000. Rainfall data source (Mitchel et al (2003) 'country climate data' Climate Research Unit (available at: http://www.cru.uea.ac.uk/~timm/data/index.html) and yield data source FAO Stat (faostat.fao.org)

Climate Change in Kenya

Climate change undoubtedly presents risks for Kenyan agriculture; not least because of the uncertainty that is associated with future changes to water availability and growing seasons. Models remain inconclusive about future rainfall patterns in East Africa in particular because of the difficulties of reliably modelling Indian Ocean sea-air dynamics and interactions between El Niño Southern Oscillation (ENSO) events and Indian Ocean Sea Surface Temperature oscillations, known as the Indian Ocean Dipole (IOD) (Pfeiffer and Dullo, 2006, Conway et al., 2007). Although, the 2011 drought, which affected parts of north-eastern Kenya, has been widely linked to the 2010 La Niña event (IRIN, 2011), a connection between La Niña events and failed MAM rainfall in East Africa has not been observed in climate records. Most cases of recent drought in Kenya (e.g. north east region in 2009, 2006-2007, and 1996-1997; across northern Kenya in 1999-2000), have resulted from cumulative low rainfall over successive rainy seasons (Ntale and Gan, 2003, Indeje et al., 2000) – whilst they might be associated with particular ENSO events, they can be more accurately explained as the product of sustained low rainfall associated with a particular sequence of ENSO coinciding with a number of other climate system oscillations (Indeje et al., 2000). As with the IOD, climate models have consistently struggled to reproduce historical ENSO patterns without artificial adjustment (Randall et al., 2007), and the knowledge about the drivers and modulators of ENSO remains incomplete.

This problematic area in climate modelling is reflected in divergent views about the direction of change in East African rainfall amounts and patterns. In the IPCC Fourth Assessment Report it states that Eastern and Africa is likely to experience a reduction in water-stress over the next 50 years (Boko et al. 2007: 435 and 445). This is supported in the 2013 IPCC Fifth Assessment Report and by a recent study conducted by Dai (2013) in which an ensemble of 11 general circulation models from the Coupled Model Intercomparison Project Phase 5 (CMIP5) were run under the Representative Concentration Pathway 4.5 (an explanation of these terms and more information on them can be found in Chapter Five), to project global soil moisture for 2080-2099, and it showed a small percentage increase (from 1980-1999 levels) in near-surface soil moisture across East Africa and a reduced drought severity index. However, a study by Williams and Funk (2011) contradicts the IPCC projections by arguing that increased diabatic heating over the Indian Ocean modulates Warm Pool circulation and will continually reduce precipitation and increase the incidence and severity of drought in eastern Africa in the future.

The information of particular relevance in terms of drought projections in Kenya (given the geographic variability in climate and crop changes), however, is data of much finer temporal and spatial resolutions: the length of individual rainy seasons, their earliness or lateness, the intensity of rainfall events, peak temperatures, and the response of crops, at local scales (Le Treut et al. 2007). Downscaling tools allow for coarse scale climate projections to be translated into geographically and temporally disaggregated rainfall. Figure 3 presents coarse resolution average daily rainfalls for 2040-2069 according to a number of climate models and emissions scenarios, the accompanying graphs show how these translate into estimates of daily rainfall projections for 2050 in two specific locations (Kapsabet (green) and Wote (red) within the districts that were the focus of the smallholder farmer workshops that are presented in Chapter Six) according to the MarkSim data tool.

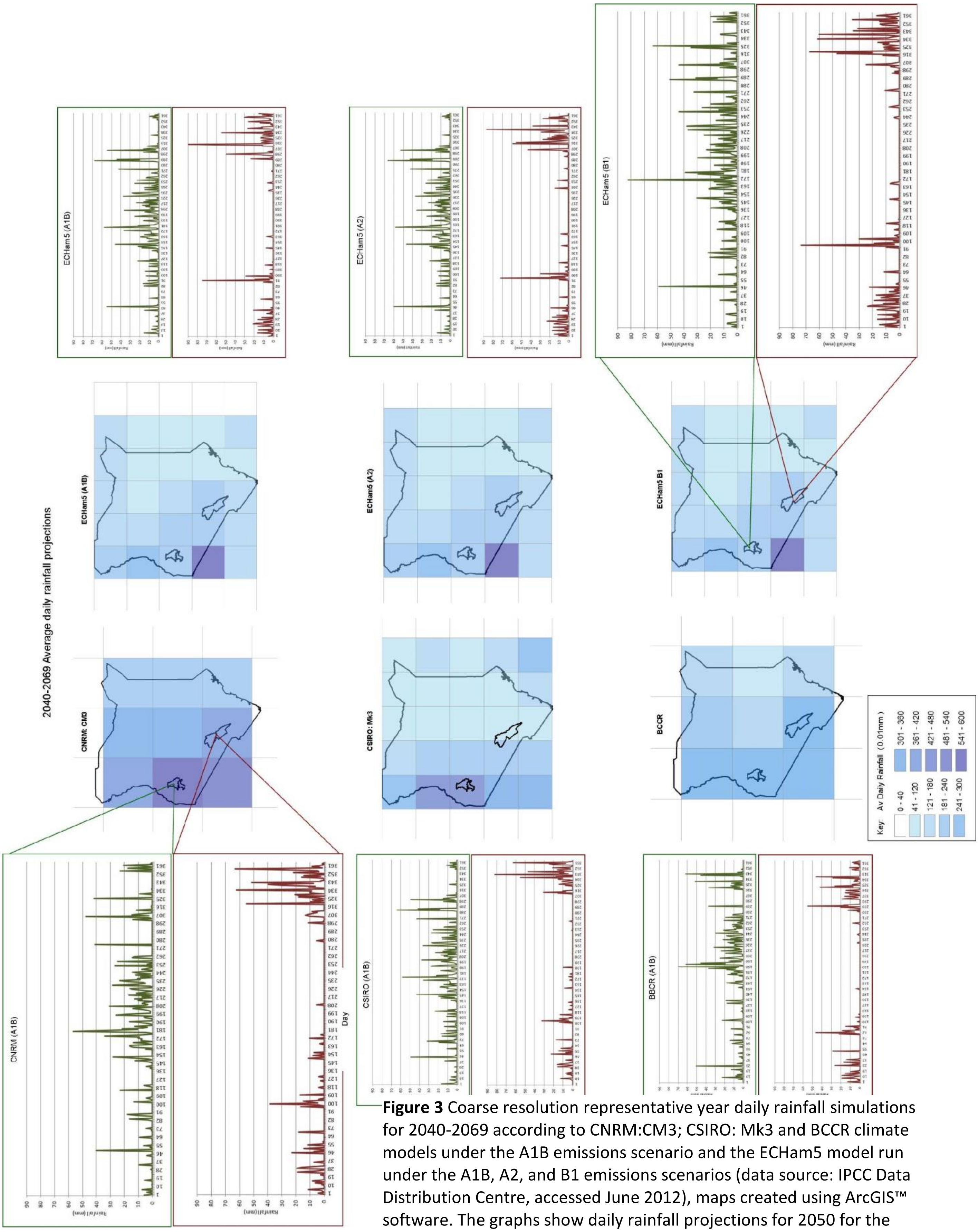

Figure 3 Coarse resolution representative year daily rainfall simulations for 2040-2069 according to CNRM:CM3; CSIRO: Mk3 and BCCR climate models under the A1B emissions scenario and the ECHam5 model run under the A1B, A2, and B1 emissions scenarios (data source: IPCC Data Distribution Centre, accessed June 2012), maps created using ArcGIS™ software. The graphs show daily rainfall projections for 2050 for the corresponding climate model and input emissions scenarios in two locations (Turbo (green) and Wote (red)) in Kenya. The data was generated using the CCAFS open-access MarkSim™ data tool.

By combining this downscaled climatic information with data on soil properties, land management, and plant development thresholds, crop models are able to postulate the impacts of climatic change on future maize yields. In Chapter Five, reference is made to a number a crop model studies that make projections relevant to changes in maize production. Unsurprisingly, given the variability in climate projections indicated in Figure 3, these climate-crop model studies present divergent and highly uncertain narratives of change in Kenyan maize agriculture, as found within a study led by the UK Meteorological Office into 'Avoiding Dangerous Climate Change':

> 'Under all the climate projections, some existing cropland areas in Kenya become less suitable for cultivation while other existing cropland areas become more suitable. The areas of increased and decreased suitability differ considerably according to the climate model used' (Met Office, 2011: 72)

The model estimates cited in this study suggest that over the 21st century, the total current cropland in Kenya is expected to experience increases in crop suitability could be anywhere from 0 to 75% under both emissions scenarios, and cropland experiencing a decrease in crop suitability could be 0 to 80% under the A1B scenario and 0 to 70% under the mitigation scenario.

A study by Thornton et al (2009), as part of CGIAR's Climate Change, Agriculture, and Food Security (CCAFS) research programme, represents the most comprehensive attempt to apply climate-crop models with specific focus on maize agriculture in eastern and southern Africa, and as such provides the highest resolution projections of change. It combined the CERES-Maize crop model with MarkSim-downscaled HadCM3 and ECHam4 GCM (with two IPCC scenario inputs: A1F1 and B1) outputs in modelling local level crop changes in East Africa. Model outputs suggested that:

> 'For maize, there are clear decreasing yield trends in the upper north-west of the region (northern Uganda, southern Sudan) and in lowland areas of Kenya and Tanzania. Increasing maize yields are found in the highland areas of central Kenya and the Great Lakes Region. There are relatively few pixels where the quadratic term is significant (i.e., where a turning point exists)' (Thornton et al., 2009)

The suggestion of these models is that yield increases may be realised in cooler and high-elevation areas whereas in lower elevation areas water stress is likely to increasingly constrain yields in response to climatic change. The projection of crop yields and maize productivity in Kenya shows geographic variability and a high degree of uncertainty that comes not just from knowledge gaps in the modelling of climatic changes, but also in incomplete information about soils, management and plant responses (Mati, 2000, Thornton et al., 2011, Thornton et al., 2010, Thornton et al., 2009, Jones and Thornton, 2003).

Climate impact models have gained a privileged position within international climate and agricultural research centres. A model-centric approach to quantifying climate impacts is evident in the CCAFS Programme as well as in the outputs of the second working group of the IPCC which continue to be dominated by the presentation of climate impact models[10]. Crop modelling is also being carried out as part of the International Crops Research Institute for the Semi-Arid Tropics' (ICRISAT) Global Theme on Agroecosystems work[11], the International Food Policy Research Institute's (IFPRI's) IMPACT 2009 project[12], FANRPAN's Strengthening Evidence-Based Climate Change Adaptation Policies (SECCAP) programme[13], and the Kenya Agricultural Research Institute's Climate Change Unit[14], amongst others. Whilst these models undoubtedly provide policy-relevant information, there are dangers in depending heavily on predictive models of agro-climatic change as a basis on which to evaluate adaptation pathways (Dessai et al., 2009). This is not only because of uncertainties about future climatic and ecological processes, which are inevitably misrepresented (and sometimes not represented at all) in model predictions (Adger et al., 2009, Dessai et al., 2009), but also because of their limitations in capturing the socially embedded and complex socio-political and cultural nature of climate adaptation (Crane et al., 2011, Crane, 2010, Adger et al., 2003, Adger et al., 2009), which is discussed more in the following sections.

Drought and Vulnerability

Drought is widely understood as a meteorological hazard that produces social risks through its impacts on water availability and food production, but, despite attempts to objectify drought through scientific indices (e.g. Palmer, 1965, McKee et al., 1993, Fischlin et al., 2007), it is a concept that has remained highly 'encultured and localised' (Hulme et al., 2009: 200). With no universally accepted definition or metric (unlike with hazards such as earthquakes, hurricanes or nuclear radiation), the reality of water shortage and low rainfall only becomes recognised as drought through locally relevant thresholds in the relationship between water availability and water use. In an agricultural system that is dominated by maize, water availability thresholds,

[10] See the Working Group II report to the IPCC's Fourth assessment Report (http://www.ipcc-wg2.gov/publications/AR4/index.html) and the Working Group II website: http://www.ipcc-wg2.gov/index.html
[11] See the Global Theme on Agroecosystems Report series available through the ICRISAT open access repository: http://oar.icrisat.org/ (accessed May 2013)
[12] http://www.ifpri.org/book-751/ourwork/program/impact-model (accessed May 2013)
[13] fanrpan.org/projects/seccap/ (accessed May 2013)
[14] www.kari.org/kccu/

such as those that represent drought, depend on the water requirements of the maize plant, and therefore it is difficult to separate a concept of drought from the society, politics, culture and economy through which agricultural systems have become dominated by and dependent on maize. Furthermore, reports and claims about the frequency and severity of drought are inevitably inseparable from figures describing the incidence of crop failure, food insecurity, poor health and sanitation, disease, conflict, and famine (Ifejika Speranza et al., 2008, Robinson and Berkes, 2010, Araya and Stroosnijder, 2011, Smucker and Wisner, 2008, Mortimore, 2010). As a social construct, our understanding of the severity of drought risk is inextricably tied to the ways in which it is experienced, and therefore to the social, economic and political structures through which vulnerability and adaptive capacity are created (Twyman et al., 2011).

Case studies of drought adaptation in Kenya (e.g. Smucker and Wisner, 2008, Campbell, 1984, Eriksen and Lind, 2009, Lind, 2003) highlight some of the ways in which social, political and economic processes, particular to regions of Kenya or the country as a whole, create agricultural drought. Eriksen and Lind (2009), for example, explain how local adaptive capacities in dryland regions of Kenya, are facilitated or constrained by national economic and political structures, and, consequently, the power of individuals to influence these structures. In particular, they point out that:

> 'The allocation of public resources in Kenya has favoured the high-potential farming areas of the former 'White Highlands' in central and western parts of the country (Leys 1975). This agrarian bias is reflected in the failure of the state to make significant investments in drylands, particularly in northern Kenya' (Eriksen and Lind, 2009: 829)

The allocation of, and access to, public resources is an important determinant of vulnerability, and the inequitable distribution of resources often represents a mechanism through which political marginalization and vulnerability become mutually reinforcing (Eriksen and Lind, 2009, Eriksen and O'Brien, 2007, Twyman et al., 2011).

Furthermore resilience and the knowledges and capacities of farmers are shaped within social networks (both within farming communities and beyond them) that determine connections to markets and flows of information (Crane et al., 2011). That political marginalization and social exclusion are often correlated with poverty, goes a long way to explaining why the IPCC reports, for example, often understand vulnerability as a product of poverty (Schneider et al., 2007).

In an attempt to move beyond environmental determinism, but simultaneously avoid the trap of substituting it for economic or social determinism, a diverse body of literature, ranging from psychology-based assessments of individual attitudes (Grothmann and Patt, 2005) to studies of social capital (Osbahr et al., 2010, Deressa et al., 2009) recognise the agency of individuals and communities as creators of their own adaptive capacity. Farmers own land management, technology adoption, and market participation choices and strategies have been shown to be subject to complex combinations of constraints, assets, and individual rationalities (Bryan et al., 2009, Deressa et al., 2009), all of which act to shape, and are therefore evident within, farmers own narratives of agricultural adaptation and change. Such narratives are, of course, subject to change, and a particularly prominent finding within studies of social capital and learning, has been that through experience, reflection and information sharing, individuals are capable not just of reacting to change, but of implementing actions and strategies that pre-emptively build resilience (Olsson et al., 2004, Patt et al., 2005, Pretty, 1995). As such, access to information, and opportunities for sharing knowledge, have become recognised as important determinants of adaptive capacity.

As vulnerability and adaptive capacity are undeniably the products of highly contextual processes, the assessment and management of drought and climate change risk might engage with these processes in a more interdisciplinary and democratic way, , in order to draw on experiences and knowledge of these contexts . Because of inevitable mismatches of scale, however, reflecting these multiple and contextualised narratives of agricultural adaptation and change within national policies and international interventions is a significant challenge.

Agricultural Policy and Climate Change Adaptation

Agriculture has been identified as a priority sector in Kenya's national climate change response. Within the National Climate Change Response Strategy (NCCRS) and subsequent National Climate Change Action Plan (NCCAP) for 2013-2017, developed by the Ministry of Environment and Mineral Resources, there is a stated commitment to investment in and development of 'climate-smart' agricultural practices, which simultaneously reduce farmers' climate vulnerability, abate emissions, and improve productivity. Within the NCCAP the 'promotion of drought tolerant crops', is listed amongst a number of target strategies, inclusive of agro-forestry, conservation agriculture, water harvesting, and insurance schemes.

Climate change priorities are evident, too, within the national Agricultural Sector Development Strategy (ASDS) which, aligned with Kenya's Vision 2030, places significant emphasis on innovation and technology for improving productivity and driving agricultural modernisation. The ASDS sets out a target growth rate (of seven per cent per year over five years) for the agriculture sector, and its stated mission for the sector is 'an innovative, commercially oriented and modern agriculture' (p. xiii); placing increasing emphasis on the privatisation and streamlining of agricultural services and processing and marketing channels. The commercialisation and modernisation of agriculture, the crux of which is increased productivity within smallholder systems, is a key component of the national economic growth targets set out in the Kenyan government's overarching Vision 2030 strategy document, and these ambitions have been supported by significant commitment to the Ministry of Agricultural and the Ministry of Higher Education, Science and Technology in recent budgets[15]. That productivity growth, agricultural modernisation and climate change adaptation are often viewed as a collective challenge to be achieved through innovation and 'climate-smart' agriculture is indicative of the way in which the uncertainties of future change and the locally-, socially- and politically-constructed nature of drought and vulnerability become lost within dominant narratives of technical change and economic growth.

In spite of the influence of the 'farmer first' movement of the 1980s (Chambers et al., 1990, Chambers and Ghildyal, 1985), which represented significant implementation of participatory breeding programmes (Morris and Bellon, 2004), the international agricultural research and development programmes of the CGIAR, have struggled, in a similar way to that of national agricultural policy, to move beyond reductionist narratives of agricultural change and engage with the contextualised constraints and rationalities of farmers. The following section begins to describe how the history of the CGIAR and negotiations over its contested mandate of providing goods for a global public, have shaped particular approaches to, and narratives of, agricultural change.

New Philanthropy and International Agricultural Research

Since the beginning of the 20th century, philanthropic foundations have aimed to address social problems and challenges through the development and delivery of goods and technologies, not provided through typical commercial channels. In the post-war era, the Rockefeller and Ford foundations drove investment in crop science and built international agricultural research

[15] As part of the African Union 2003 Maputo Declaration on Agriculture and Food Security in Africa, the Kenyan government made a commitment to spending 10 per cent of its national budgetary resources on agriculture. The Science, Technology, and Innovation Bill approved by the cabinet in 2013, also lays out plans to increase investment in science to 2 per cent of national gross domestic product.

centres. A combination of technology transfer and advances in crop breeding and genetic science, which resulted in the Asian Green Revolution of the 1960s and 1970s, became a model of the operations of institutions such as the International Maize and Wheat improvement Centre (CIMMYT) and the International Rice Research Institute (IRRI), the founding centres of the CGIAR. The green revolution narrative, which remains central to much of the CGIAR's operations and has been advanced by other philanthropic donors such as the Bill and Melinda Gates Foundation (BMGF), is one in which the modernisation of a subsistence smallholder farming system is achieved from the basis of a public research endeavour.

The strategic priorities of the CGIAR are guided by an Independent Science and Partnership Council (ISPC), described as a 'panel of world-class scientific experts… [that] advise CGIAR funders on strategic scientific issues and harness the best of global science to support the goals of the international agricultural research community'[16]. Dalrymple (2008) justifies a research system in which the agendas and priorities are primarily set by scientific experts:

> 'Some would make the process less supply (scientist) -driven and more demand (user) -driven. While this approach is quite appropriate at the local level, it becomes less so at the international or global level where greater emphasis is given to problems of broad importance and longer term research.' (Dalrymple, 2008: 358)

Brooks et al (2009) recognise that philanthropic foundations have an autonomy, not afforded to state organisations, that gives them both power to define development agendas (and prioritise certain public needs or social benefits), and a freedom to invest in new and untested research and innovation. However, in contradiction to this freedom, they recognise a common conservative character to the operations of the BMGF, the Rockefeller Foundation and others, 'whose favoured strategy marries an enduring faith in science-based solutions with a 'business minded' approach to philanthropic giving' (Brooks, 2011: 69) and who predominantly target improvements in efficiency and productivity within the limitations of the status quo, rather than seeking to bring about radical social changes. There is certainly evidence of a persistence of the corporate language and style of 'venture philanthropy' (Edwards, 2008), and Dalrymple suggests that this 'impact-at-scale'-type approach to the provision of public goods, justifies a top-down approach to the setting of priorities and agendas within the CGIAR.

However, Sumberg et al (Sumberg et al., 2012) explain that a growing critique of the inequities of the Green Revolution in the 1980s had significant influence in promoting issues of social

[16] http://www.sciencecouncil.cgiar.org/ (accessed June 2013)

priorities and justice within the agronomic research and a participatory agenda, and new interest in participatory and 'farmer first' (Chambers et al., 1990) agricultural research emerged in response. CGIAR institutions integrated and institutionalised innovative practices of participatory breeding and varietal selection within their crop development strategies, with the aim of both better targeting the needs of the poorest farmers and improving the uptake of end-product technologies.

The CGIAR's recent prioritisation of issues of agricultural governance, gender equality, social justice, and socio-ecological resilience, within its research agendas (e.g. in its CCAFS research programme), have seen a broadening out of its remit beyond the advancement of technological pathways of change. Work within the CCAFS group, in particular, includes research into community-based adaptation and livelihoods diversification. These broader priorities, which are explicated in the CGIAR's 2004 charter and in the ongoing restructuring of research programmes, necessarily require context-specific and 'demand driven' (to use the language of Dalrymple) approaches – such as that of the extensive CCAFS village-level survey work – that might not necessarily have global spill-over. The extent to which changing priorities within the CGIAR are seeing a movement away from its initial mandate of providing global goods is subject to debate. Dalrymple argues that a weakening of the autonomy and power of the Science Council and the necessity of branching out from the 'green revolution' objectives of the group is lessening the CGIAR impact on societal needs (Dalrymple, 2008), whilst Brooks conversely identifies failures in addressing such needs that are associated with the persistent hierarchies of epistemology and target-driven technocracy in the system (Brooks, 2011):

> 'Two contrasting views have been expressed about the desirability of this shift in priorities. Some donors see the expansion of activity as responsive to current needs and problems and indeed have specifically targeted funds for research on the expanded agenda. Others see the shift as a dangerous abandonment of the proven capabilities of the CGIAR in favour of the pursuit of fashionable goals by doubtfully productive means.' (Gardner and Lesser, 2003: 692)

There has also been some commentary on the effectiveness with which the CGIAR has succeeded in reorienting towards more localised social priorities. Cernea (2005), Cleveland (2008), and Fernando (2007), for example, have expressed concern over the continued marginalisation of social sciences within the CGIAR system, and Dalrymple (2008: 358-359) suggests that 'the CGIAR is basically a biological research organisation tempered by economic and social considerations'.

Judith Rodin (then president of the Rockefeller foundation) suggested at the 2007 Global Philanthropy Forum, that the past decade has seen the emergence of a new model of philanthropy that is driving the operations of international agricultural research in which, whilst emphasis on the provision of social benefits at scale persists, market channels are increasingly favoured for achieving this delivery in a way that is both efficient and more directly fosters a transition toward smallholder engagement in the market economy (Rodin in Brilliant et al., 2007). Research, technology development, and dissemination, funded through philanthropic donors, increasingly takes place in partnership with private sector actors, who often hold expertise and capacities for work on state-of-the-art technologies as well as means to longer term commercialisation and sustainability (again without radical changes to social order or the capitalist economy) (Ferroni and Castle, 2011).

In the case of WEMA, as in many other transgenic crop development and other biotechnology programmes[17], the technology is being advanced through a public-private partnership (PPP), in which the Kenyan Agricultural Research Institute (KARI) and CGIAR institutions represent a public partner and multinational companies such as Monsanto and Syngenta come from the private sector. Muraguri (2010) explains that 'PPPs in agricultural biotechnology currently enjoy critical acclaim in both policy and scholarly circles' (p. 289) for the knowledge and technology exchange efficiencies that such partnerships afford (Van der Meer, 2002, Mitchell-Weaver and Manning, 1991, Muraguri, 2010, Blankenburg, 2000, IPPR Commission on Public Private Partnerships, 2001, Chataway, 2005, Brinkerhoff and Brinkerhoff, 2004). The emphasis placed on these partnership within the operations of CGIAR were acknowledged in the 2011 CGIAR strategy, which points out to the importance of working in such partnerships as a reason for reconsidering the efficiency and outputs of its research, such that it becomes an 'effective investment':

> 'Private sector research is playing a growing role and although its deployment in low income countries is still very uncommon, it holds potential capacities that cannot continue to be ignored. These changes have been in the making for a long time and now require that the CGIAR re-examine its business practices so it can continue to be an effective investment.' (CGIAR Strategy and Results Framework, 2011: 17)

Private partners may enter into projects in much the same way as philanthropic donors; through a charitable branch of the organisation (e.g. the Syngenta Foundation in the case of Golden Rice,

[17] Some of the key GM products currently being developed particularly for African agriculture, through public-private partnerships brokered by the African Agricultural Technology Foundation, include Maruca-resistant cowpeas, aflotoxin reduction in maize grains, bacterial wilt-resistant bananas, vitamin-enriched rice, and drought- and insect-resistant cereal crops.

or the Monsanto Sustainable Yields Initiative in the case of WEMA). The difference, however, is that the knowledge and technologies contributed within these partnerships often simultaneously have a commercial value for the private actor, who also operate in markets in which there is an ability and willingness to pay for knowledge and technologies.

The CGIAR's public goods mandate has long manifest in making the knowledge and resources developed through its programmes widely available and accessible. Within CIMMYT, this sentiment has traditionally been reflected in the approach that it has taken to its germplasm and plant genetic materials, which have been made available to researchers and plant breeders through in-trust agreements with the FAO since 1994 and this was formalised through the International Treaty for Plant Genetic Resources adopted by the FAO Council 2001, with the CGIAR centres using Standard Material Transfer Agreements (SMTAs) through which to share and disseminate their material. These SMTAs have been recently designed not just to open up access to materials, but also to remove restrictions on how the materials are used. Across the CGIAR, this ethos has also been applied to making research data openly accessible, an intent that was restated and reinforced in the 2013 Open Access Policy.

However, public-private partnerships critically depend on much more carefully brokered knowledge and technology transfer agreements. Byerlee and Fischer (2002) explain that such agreements can take on a number of forms, depending on the nature of collaboration between public and private partners. The 'Humanitarian License' of the Golden Rice initiative, which is overseen by a Humanitarian Board, was an innovative way of negotiating the transfer of private goods for public application (Brooks, 2011), and it has been adopted in an altered form within the WEMA project, through the African Agricultural Technology Foundation (AATF). In essence, these brokered agreements grant public research institutions free access to the proprietary technologies for breeding, providing that their application is restricted to humanitarian outputs (e.g. through royalty-free seed supply chains or restrictions on who can access the end-products) (Brooks, 2011). In such circumstances, the distinction between public and private goods is a constructed one, defined by the limitations that institutions and policies place on the use, transfer and accessibility of the knowledge and technology (Spielman, 2007, Dalrymple, 2006) rather than their inherent nature.

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In relation to such goods, this problematic public-private distinction, has been replaced by the popularisation of 'pro-poor' as a way of describing interventions that place emphasis on the achievement of poverty reduction, food security and social justice; and this 'pro-poor' discourse is increasingly associated with agricultural technologies for smallholder farmers (Scoones, 2002, Chataway, 2005, Glover, 2009, de Janvry and Sadoulet, 2002, Spielman, 2007). The discourse emerged within a cluster of reports by international organisations advocating agricultural biotechnology (International Food Policy Research Institute (1999), the Nuffield Council on Bioethics (1999), and the Food and Agricultural Organization (2004)) and has consequently acted to situate agricultural biotechnology as a technology of public interest in relation to a purposefully conceptualised public (Jansen and Gupta, 2009). Ron Herring, in 2007, argued that an understanding of the role of agricultural biotechnology as a pro-poor international development strategy has come to be accepted as the 'standard narrative of biotechnology' (2007: 7). Of course, within public-private biotechnology and crop breeding programmes, a significant responsibility is placed on co-ordinators, such as the Humanitarian Board or AATF, to define (and set boundaries around) publics and public needs to be addressed through the provision of its technologies (Dalrymple, 2006). In this respect, the construction of narratives around technological intervention, which define social problems and solutions, play an important role in justifying and legitimising interventions.

The DTMA and WEMA Initiatives

The 'Drought Tolerant Maize for Africa' (DTMA) initiative was established in 2006 through a grant made by the Bill and Melinda Gates foundation, as well as financial support from DFID and USAID to CIMMYT and the International Institute for Tropical Agriculture (IITA)[18]. The project involves collaborative work with publicly-supported national agricultural research centres in thirteen African countries[19], such as the KARI – a semi-autonomous government-funded institution, working in partnership with the Ministry of Agriculture, which participates in a huge portfolio of research activity – with the aim of developing, field testing, and marketing drought tolerant maize varieties for use by smallholder farmers[20]. As well as the development of germplasm, the DTMA project involves research, development, and capacity building activities, inclusive of work with seed producers and seed supply systems as well as extension work through community and farmer groups[21].

In 2007 a second project, initially titled DTMA II, but later changed to the Water Efficient Maize for Africa project, was established through another BMGF grant, but with a smaller sphere of

[18] A background to the DTMA project is available at http://dtma.cimmyt.org/index.php/about/background (accessed May 2013)
[19] Angola, Benin, Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Nigeria, Tanzania, Uganda, Zambia, and Zimbabwe
[20] http://dtma.cimmyt.org/index.php/about/background (accessed May 2013)
[21] DTMA research reports document this range of research and re available at: http://dtma.cimmyt.org/index.php/publications?start=35 (accessed May 2013)

operation, just five countries – Kenya, Mozambique, South Africa, Tanzania, and Uganda. WEMA seeks to enhance DTMA germplasm through the use of transgenic techniques, with a particular focus on the use of marker assisted breeding tools and the insertion of shock-resistant genes into maize DNA[22].

The project is managed and funded by many of the same partners as in DTMA, except it is coordinated by the AATF. AATF is a not-for-profit organisation, funded through the Rockefeller Foundation, USAID and DFID (as well as project donors), that coordinates public-private partnerships aimed at delivering technologies that will meet the 'priority needs identified by smallholder farmers' in Africa. It was established following Rockefeller Foundation funded research into the improvement of technology transfer for the achievement of the United Nation's Millennium Development Goals (MDGs) in Africa, and its mandate was created with the joint participation of the CGIAR, seed companies and other technology organisations.

Within WEMA, CIMMYT and national agricultural research centres (in the case of Kenya this is KARI) are partnering with a private sector actor, Monsanto PLC, which holds the gene technology and expertise. The gene (a 'cold shock' protein B(CspB)) of particular interest in the WEMA project has been isolated from the bacterium *Bacillus subtilis* which is commonly found in soils. Whilst it has been identified as conferring cold stress in bacteria, tests have indicated that it has the potential to confer more general stress tolerant characteristics within plants[23] – Monsanto hold a number of patents over techniques for isolating and transferring this gene sequence, and have granted special permission and technologies for its use in the WEMA project.

Within Monsanto, WEMA activities fall under the charitable 'Sustainable Yield Initiative' which has the explicit aim to 'produce more, conserve more and improve farmer's lives'[24]. The Sustainable Yields Initiative is the corporate social responsibility face of Monsanto and was established in 2008 as a means of availing its technology to resource poor farmers that otherwise would not have access. The Sustainable Yields Initiative continues to be an important element of the company's plans to improve its public image and promote the social acceptability of modern biotechnology. However, Monsanto has a particularly bad reputation amongst civil society groups and in the anti-biotech lobby, because of the perception of the pursuance of

[22] Personal Correspondence with members of CIMMYT and AATF, triangulated through a review of project documents available at: http://wema.aatf-africa.org/about-wema-project
[23] More details about the specific genetic modification process relating to WEMA are included in the following paper [CASTIGLIONI, P., WARNER, D., BENSEN, R. J., ANSTROM, D. C., HARRISON, J., STOECKER, M., ABAD, M., KUMAR, G., SALVADOR, S. & D'ORDINE, R. 2008. Bacterial RNA chaperones confer abiotic stress tolerance in plants and improved grain yield in maize under water-limited conditions. *Plant Physiology,* 147**,** 446-455.]
[24] http://www.monsanto.com/improvingagriculture/Pages/default.aspx/

profit-making and monopolization at the expense of farmer livelihoods (e.g. the impacts of aggressive patenting on the ownership of intellectual property and local crop breeding, and the development of GM varieties that essentially create reliance on Monsanto chemical inputs (e.g. roundup ready crops)). The Monsanto 'Smallholder Programme', a precursor to the Sustainable Yields Initiative, which ran between 1999 and 2002, has been criticised for its desire to establish new markets for genetically modified crops by advancing a narrative that 'creat[ed] and promot[ed] a positive association between GM crops and smallholder farmers' (Glover, 2007:3).

The first phase of the WEMA project, which ran from 2008 to 2012, focused on the selection of germplasm, obtaining permissions to import transgenic events (from Monsanto's US laboratories) and begin field trials of WEMA varieties[25]. These tasks were achieved to different extents across the five operating countries, largely as result of differences in the structures of (or the absence of structures) of regulation across the countries[26]. The second phase, which began in 2013 and ends in 2017, aims, in those countries in which the varieties have been tested, to obtain permissions for environmental release and on-farm trials. It is also hoped that research will begin on stacking genetic traits, specifically combining the drought tolerance gene with Bt insect resistance. The Insect Resistant Maize for Africa (IRMA) project, which began in 2005, is a companion to WEMA, being jointly led by CIMMYT and national agricultural research centres, and funded through the Syngenta Foundation. One of the IRMA project focuses is on the testing and development of Bt Maize (recently receiving permission to conduct confined field trials of MON810 maize in Kenya) and it is through this project that CIMMYT has conducted some studies of consumer and stakeholder perceptions of, and attitudes towards, GMOs. The eventual plan for CIMMYT, through IRMA and WEMA, is to attempt to combine water efficient and insect resistant genes within maize germplasm. A third phase of the WEMA initiative will depend on funding and the success of phase two, but may continue to develop and disseminate these stacked trait varieties. In addition to its technical component, the WEMA project seeks to: develop the capacity of research institutes (such as KARI) to conduct risk assessments and prepare safety data documents in order to meet regulatory requirements for the commercial release of seeds; promote public awareness and consumer acceptance; and facilitate rapid deployment of the seed products to smallholders.

[25] WEMA Progress Report 2008-2011 avaiable at http://www.aatf-africa.org/userfiles/WEMA-Progress-Report_2008-2011.pdf (accessed May 2013)

[26] Personal Communication, AATF Representative (August 2012) and triangulated through the 'Biotech Information Resources' at the ISAAA-AfriCentre – available at: http://www.isaaa.org/resources/publications/briefs/44/default.asp and government websites for each of the 5 WEMA countries

The DTMA technology pipeline has been prolific, with a total of 113 drought tolerant varieties (both hybrid and open-pollinated varieties) from DTMA partners being commercially released within 10 countries over the period of 2007 to 2012[27], with growing rates of uptake being reported[28]. The outputs of the WEMA initiative have so far been modest in comparison. In line with the project schedule, the commercial release of its first non-transgenic hybrids is due in 2014, but the prospects for release of transgenic varieties remains uncertain, with national biosafety regulatory protocols placing restrictions on the trialling of these varieties and, in several WEMA countries, regulatory frameworks for the environmental release and consumption of GM crops are not established or represent significant barriers to the WEMA technology delivery pipeline. Data on crop performance from those transgenic trials that have taken place has not yet been made available.

The viability of the DTMA/WEMA narrative, and its particular technology-based future agriculture, is critically subject to its compatibility with national-level narratives of technology regulation. In the case of modern biotechnologies in particular, national governments act to define and enforce regulations around the testing, release, transfer and marketing of technologies, which can further act to shape who, and what, the technology is for. The following section provides background information about the development and regulation of genetically modified crops, both globally and in Kenya specifically. It begins to describe how contestations between discourses of social 'goods' and social 'risks' (as ways of defining the technology) are playing out within ongoing policy debates over biosafety, with the potential problem of emerging narratives that are incompatible with the WEMA narrative.

Genetically Modified Crops: Risk and Regulation

> 'Whether or not transgenic technology… is in the public interest depends on how one conceptualises the public, how one couches the alternatives, the normative position one takes on uncertainty and risk, and the projections one makes from an inevitably incomplete science.' (Herring, 2007: 24)

Genetically modified[29] (GM) crops are characterised by complex and multi-sited scientific development that is poorly understood and communicated outside of the industry (Frewer et al., 1998, Frewer et al., 2002); low levels of public trust in the related industrial actors and regulating institutions (Savadori et al., 2004, Priest et al., 2003); and a multiplicity of related risks and

[27] http://dtma.cimmyt.org/index.php/varieties/dt-maize-varieties

[28] See DTMA (2012) Brief: The Drought Tolerant Maize for Africa project: Six years of addressing African smallholder farmers' needs (available at: http://dtma.cimmyt.org/index.php/press-room/dtma-briefs)

[29] A glossary of terms relating to genetic modification and modern biotechnology can be found in the appendix

uncertainties (Stirling, 2003, Stirling, 2007, Wynne, 2002, Levidow, 1998, Lash, 2000). As a consequence, policy debates about the regulation of GM crops, which inevitably shape the development of technology and its role within future agriculture, largely depend on incomplete knowledge about the impacts of the technology and contestations over the nature of its social benefits and risks. Table 1 provides examples of some of the positive and negative narratives associated with the introduction of GM crops into agri-food systems (Aerni, 2005, Wolfenbarger and Phifer, 2000, Peterson et al., 2000, Ferber, 1999, Pretty, 2001).

Table 1 Positive and negative narratives relating to the introduction of genetically modified crops into farming systems

	Positive Narratives	**Negative Narratives**
Health	Biofortification in food crops leads to nutrient- and vitamin- enhancement of cereals and improved dietary health (e.g. Beyer, 2010)	The bacterial uptake of GM plasmids results in antibiotic resistance and new allergens become expressed in food crops
Economic/Livelihood	The development of high-yielding and resilient crops leads to increases in production	Farmers become tied into reliance on GM seeds and unserviceable contracts with biotech corporations (e.g. Shiva, 2008)
Environmental	New crops require less fertiliser and pesticide inputs	Cross-pollinations from herbicide resistant plants produce new super-weeds
	Productivity increases reduce pressure on non-agricultural land	Insect resistant crops impact negatively on non-target insects and ecological diversity
Societal/Cultural	Reliable yields facilitate agricultural investment and modernisation	Traditional breeding and seed storage practices, and heritage varieties, become lost as a result of market monopolisation and patenting (Kloppenburg, 2010, Shiva, 1997)

As Herring point out, each of these narratives about the introduction of GM crops contains implicit conceptualisations of publics and public interest, and different assumption-based projections into a future of uncertain impacts (both negative and positive). These varied narratives, which represent very different rationales for regulation, are advanced within often highly polarised national debates by actors and groups that favour particular policy outcomes. These debates have resulted in different outcomes in different parts of the world. The 2000 Cartagena Protocol on Biosafety (a supplement to the UN Convention on Biological Diversity) essentially outlined the rights of countries to restrict the entry of GMO products into their markets on the basis of their own judgements about uncertainties and socio-economic impacts of the technology (it also emphasizes the importance of detailed information exchange prior to countries consenting to the import of GMOs).

The polarisation between US and UK (broadly representative of the EU) approaches to GMO regulation has been attributed to differences in: public trust in regulators (Löfstedt and Vogel, 2001); the political influence and organisation of the industrial and biotechnology lobby (Dunlop, 2000); collective action of anti-GMO NGOs (Bernauer and Meins, 2003); the cultural importance placed on small-scale farming (Prakash and Kollman, 2003); exposure to timely biological hazards (particularly the BSE crisis) (Prakash and Kollman, 2003); and the influence of policy moments such as the European Union's mandatory labelling decision in 1997 (Millstone, 2000). The US is often characterised within this literature as a state whose role is to facilitate international trade, whilst the UK is considered to be a state that is primarily concerned with limiting social risk (Jasanoff, 1995, Dunlop, 2000, Newell, 2002).

National autonomy over GM decisions has been challenged by international trade disputes, and in 2006 the World Trade Organisation (drawing on its Sanitary-Phytosanitary (SPS) Agreement and the Technical Barriers to Trade Agreement) judged that the European Union's *de facto* moratorium on approving new GM products, which ran from 1998 to 2004 and was based on broad concerns about genetic modification rather than specific issues with individual products, was illegal as it did not have a clear scientific basis.

It is within this international context of contested politics that GMOs have been introduced to, and have begun to be developed within, the African continent, again with variation in the policy positions taken, and investments made, by national governments. South Africa was the first African nation to permit the commercial production a GMO (Monsanto-developed Bt cotton) and a GM subsistence crop GMO (Bt maize) at the beginning of the 21st century[30], it was also a pioneer in the development of biosfatey legislation which, unlike subsequent biosafety laws in other African countries was developed largely independently of external capacity building efforts (Ayele, 2007, Mayet, 2007, Gupta and Falkner, 2005). To date, only two other African countries have approved commercial GM crop production (Burkina Faso (in West Africa) and Egypt (in North Africa))[31]. Since the late 1990s, a number of countries have initiated GM research programmes as part of national and regional strategies for agricultural development, such as the

[30] The development of Bt cotton in South Africa began in 1990 and it was approved for commercial release in 1997, GM maize was subsequently approved in 1998 and GM soybean released in 2001 -- [GOUSE, M., PRAY, C. E., KIRSTEN, J. & SCHIMMELPFENNIG, D. 2005. A GM subsistence crop in Africa: the case of Bt white maize in South Africa. *International Journal of Biotechnology,* 7**,** 84-94, GOUSE, M., KIRSTEN, J. F. & JENKINS, L. 2003. Bt cotton in South Africa: Adoption and the impact on farm incomes amongst small-scale and large scale farmers. *Agrekon,* 42**,** 15-29, JAMES, C. 2003. Global status of commercialized transgenic crops: 2002. *ISAAA briefs,* 21.]

[31] ISAAA (2012) 'Biotech Crops in Africa: The Final Frontier' (available at http://africenter.isaaa.org/index.php/publications/1-biotech-crops-in-africa-the-final-frontier; accessed June 2013)

NEPAD (New Partnership for Africa's Development) Comprehensive African Agriculture Development Programme (CAADP)[32], and through programmes under the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) and the CGIAR (Okusu, 2009). This has led to rapid growth in university programmes, the development of research facilities, and international and public-private research collaborations across the continent[33].

In many cases, national research and development programmes, and in some cases field trials of GM crops, have been carried out in the absence, or prior to the development, of national biosafety regulatory frameworks, often regulated instead according to institutional guidelines or non-legally-binding guidelines[34]. The Cartagena Protocol has been the initial impetus for the development of national policy making, but in most African countries it has been a slow process, pushed along by the efforts of external groups and bilateral capacity building interventions. These interventions themselves have been subject to a lot of academic commentary (Muraguri et al., 2003, Mtui, 2012, Zerbe, 2008, Kingiri and Ayele, 2009, Kameri-Mbote, 2002, Paarlberg, 2008, Karembu et al., 2010). Robert Paarlberg (2009) made a widely cited argument that European governments, backed by lobby groups, supported the inclusion of a precautionary principle within the Cartagena Protocol and are keeping GM crops out of Africa by pushing a precautionary stance within policy making. Paarlberg's argument, however, overlooks the fact that in those African states most advanced in the development of biosafety legislation (e.g. Kenya, Nigeria, South Africa, Zimbabwe), capacity building has been largely funded by states that have not ratified the Cartagena Protocol and have a founded interest in promoting international GMO trade (Gupta and Falkner, 2005)[35]. To this end, the Programme for Biosafety Systems (PBS), funded by, the United States Agency for International Development (USAID) through the

[32] CCADP Pillar 4 'aims to improve agricultural research and systems in order to disseminate appropriate new technologies' (http://www.nepad-caadp.net/pillar-4.php)

[33] Resources on the status of biotechnology in Africa are available through NEPAD at http://www.nepadbiosafety.net/subjects/biotechnology/status-of-crop-biotechnology-in-africa; and in the 2012 ISAAA report 'Biotech Crops in Africa: The Final Frontier' (available at http://africenter.isaaa.org/index.php/publications/1-biotech-crops-in-africa-the-final-frontier)

[34] In the cases of Kenya, Burkina Faso, South Africa, Zimbabwe and others in country research and development work within research institutions and universities prior to the formalisation of National Biosafety Frameworks (ISAAA 'global status' reports: http://www.isaaa.org/resources/publications/briefs/default.asp; and AATF report on the status of regulation of GM crops in countries in sub-Saharan Africa: http://www.aatf-africa.org/userfiles/Status-Regulations-GM-Crops_Africa.pdf)

[35] Paarlberg's arguments also depend on a narrow understanding of the precautionary principle (i.e. as being inherently tied to the anti-GM sentiments of groups such as IFOAM rather than being developmental and progressive (Stirling 2007)) and a misinterpretation of the Cartagena protocol (i.e. as trade restricting rather than promoting autonomy and choice)

International Food Policy Research Institute (IFPRI)[36] has played a significant role in assisting the development of biosafety regulations in African countries (Karembu et al., 2010).

African nations are certainly not without agency in determining their own narratives of agricultural development, and determining what role GMOs should play within it. Political interests and protests come from within countries just as they do from without, and regional trading groups such as COMESA also have important influence[37]. This agency is demonstrated in the significant input that a 'like-minded group' of African nations had in the drafting of the Cartagena protocol and in controversial decisions, such as that taken by the Zambian government in 2002 to reject GM food aid during a famine emergency[38]. However, Kingiri and Ayele's (2009) argument that 'Kenya must develop home-grown biotechnology and biosafety capacity in order to instil 'ownership' of thinking into the minds of scientists and policy makers, thereby enhancing public trust' (p. 138), is slightly naïve. The reality of the global context, shaped as it is through trade, aid, and other international relations, is that domestic biosafety regulation politics cannot be isolated from a number of external priorities and stakeholders.

Of the East African nations, Kenya is the most advanced in terms of both biotechnological research and biosafety legislation[39], in part because a relatively liberal and democratic government have, for many years, made it an attractive investment country for technology developers, and Nairobi has grown into a headquarters city for many regional research and diplomatic organisations, contributing to investment in an advanced and maintained infrastructure. Centres of Excellence in biotechnology research situated in Kenya include organisations under the CGIAR including the International Livestock Research Institute (which hosts the Bio-Sciences East and Central Africa (BeCA) and the African Agricultural Technology Foundation (AATF)), CIMMYT, The World Agroforestry Centre, and IFPRI, as well as the International Centre for Insect Physiology and Ecology (ICIPE). Biotechnology facilities and related courses have been developed at many of Kenya's national universities including the University of Nairobi's Institute of Biotechnology and Bioinformatics and the College of Agriculture and Veterinary Science, the Jomo Kenyatta University of Agriculture and Technology's Institute of Biotechnology Research, and Moi University's School of Biotechnology

[36] http://pbs.ifpri.info/
[37] e.g. through the Regional Approach to Biotechnology and Biosafety Policy in Eastern and Southern Africa (RABESA) initiative (http://africenter.isaaa.org/index.php/policy-outreach/rabesa)
[38] BBC News: 'Famine-hit Zambia rejects GM food aid (http://news.bbc.co.uk/1/hi/world/africa/2371675.stm); The Telegraph: 'Starving Zambia rejects America's GM maize' (http://www.telegraph.co.uk/news/worldnews/africaandindianocean/zambia/1411713/Starving-Zambia-rejects-Americas-GM-maize.html)
[39] It was the first of the East African countries to establish a formalised biosafety framework and several recent and on-going GM crop development projects (Box 2)

and Agriculture. The publically-funded Kenya Agricultural Research Institute has a dedicated Biotechnology Centre, with state-of-the-art facilities. In conjunction with Nairobi-based Biotechnology NGOs, such as the International Service for the Acquisition of Agri-biotechnology Applications (ISAAA), the African Biotechnology Stakeholders Forum (ABSF), the Africa Harvest Biotech Foundation International, and the Agricultural Biotechnology Network in Africa (ABNETA), the Kenyan government has implemented a number of public outreach initiatives including the BioAWARE programme and the Open Forum on Agricultural Biotechnology (OFAB).

Specific GM crops being developed and trialled in Kenya include insect and drought resistant maize, insect resistant cotton, mosaic virus resistant cassava and viral resistant sweet potato (James, 2003, Karembu et al., 2009). Box 2 gives details of the organisations involved in each of these projects and their current status. No GM crops have, as yet been approved for commercial release in the country, but the regulatory protocols and infrastructure for application and approval and subsequent monitoring are in place via the National Biosafety Authority (created in fulfilment of the 2009 Biosafety Act) and subsidiary regulatory agencies (KEPHIS, KEBS, NEMA[40]).

Box 1: Recent and On-going GM crop development projects in Kenya

Maize	Insect Resistance	KARI, CIMMYT, Monsanto, Syngenta	(Ongoing confined field trials)
-	Drought Tolerance	KARI, CIMMYT, Monsanto	(Ongoing confined field trials)
Cotton	Insect Resistance	KARI, Monsanto	(Ongoing confined field trials)
Cassava	Mosaic Virus Resistance	KARI, Danforth Centre	(Completed trials)
Sweet Potato	Viral Resistance	KARI, Monsanto, Danforth Centre	(Completed trials)

Kenya's Biosafety Act[41] was passed in 2009, almost a decade after it became the first signatory state to the Cartagena Protocol on Biosafety[42]. The Biosafety Act formalises a system of regulation that is overseen by the National Biosafety Authority within the National Council for Science and Technology, who are charged with considering applications for the confined trialling, release and import and export of GMOs[43]. A number of regulations have been developed under the Biosafety Act to guide these specific activities including Contained Use (2011), Environmental Release (2011), Import, Export and Transit (2011), Labelling and Traceability (2012), and

[40] Kenya Plant and Health Inspectorate Services (KEPHIS); Kenya Bureau of Standards (KEBS);National Environment Management Authority (NEMA)
[41] 2009 Biosafety Act: http://www.kenyalaw.org/Downloads/Acts/The_Biosafety_Act_2009.pdf (accessed on 8/11/11)
[42] Text of the Cartagena Protocol on Biosafety: http://bch.cbd.int/protocol/text/ (accessed on 8/11/11)
[43] http://www.biosafetykenya.go.ke/ (accessed June 2013)

Transport (2013)[44]. Intermediate regulatory agencies, Institutional Biosafety Committees (IBCs), have been established within large biotechnology institutions, such as KARI, to internally coordinate biosafety applications and oversee and enforce biosafety obligations (e.g. the risk assessment documentation).

The nature and content of Kenyan GMO regulations, and therefore the narratives that win out in GM policy debates, have important implications for the success of the WEMA project, for example, by defining restrictions and obligations for product development, trialling, and eventual release. As such, actors within WEMA (e.g. members of the regulatory team) are promoting the WEMA narrative (of a pro-poor technology of social benefits) within on-going policy debates, in the hope that regulation will ultimately be facilitating of it. This situation begins to demonstrate the interconnected nature and interdependencies of the case studies and narratives of this research.

Conclusion

The intersection between modern biotechnologies, climate change, poverty and food security is associated with a multiplicity of uncertainties and risks which are differently framed and weighed up by different actors across a vast network of stakeholders in the future of Kenyan maize agriculture. This background chapter has revealed a complex combination of political, social and climatic contexts in which alternative narratives are constructed. Evident across the case studies presented in this thesis are important interdependencies between these varied actors and narratives. Climatic futures inevitably constrain farmers' strategies, which in turn shape technology adoption and development. Similarly (and to move in the opposite direction to the sequence of this thesis), regulatory narratives frame technology developments, which influence farmers' adaptation strategies. Through the analysis of knowledge claims and interconnections and points of contention between alternative narratives of agricultural change, both within the case studies and between them, this thesis aims to contribute to a laying of the necessary groundwork for a more deliberative construction of, and an opening up to alternative, narratives of agricultural change. The following chapter sets out a conceptual framework for this analysis.

[44] The text of each of these regulations is available at: http://www.biosafetykenya.go.ke/index.php?option=com_content&view=category&layout=blog&id=84&Itemid=498 (accessed June 2013)

Chapter Three: Conceptual Framework

Unpacking Incomplete Knowledge and Governing an Uncertain Future

Contemporary agriculture operates within a dynamic context that is comprised of climates, technologies, regulations, economies, and livelihood strategies, the future trajectories of which are both interdependent and unknown. This thesis focuses on how different assumptions about these trajectories produce different narratives of change in Kenyan maize agriculture, and engages with those actors that are simultaneously constructing narratives of change and exercising their agency to realise those narratives. A narrative is understood here as a storyline about the future based on assumptions about the trajectories of one or more dynamic components (e.g. the economy, politics, the environment, livelihoods etc.) often in relation to coupled problems and responses (Leach et al., 2010). The potential for a narrative to translate into successful agricultural change, inevitably depends on the correctness of its assumptions across these dynamics, and, particularly in relation of trajectories over which others have the agency, it will depend on the decisions of a range of actors to conform to the narrative; to implement supporting policies, to build appropriate capacities, to adopt technologies, to communicate necessary information, and so on.

There are a number of potential mechanisms to explain the divergence or convergence of narratives of different actors and these can be broadly classified as being characterised by: coercion and closing down alternatives; learning and cognitive change; and resistance. There is an important role to be played by knowledge and evidence, which can be a means of legitimization and exclusion, a driver of learning, and grounds for objection. The research presented here engages with points of narrative divergence and convergence in order to understand how these mechanisms are being played out in the negotiation of Kenya's agricultural future between a variety of actors, including climate scientists, smallholder farmers, crop breeders and policy makers, and it particularly focuses on the roles of knowledge and evidence within these negotiations.

In this chapter, the conceptual framework of the research is laid out. An explanation of the meanings and origins of, and a justification for the use of, the particular terminology used in the thesis is given. The chapter also contains a review of literature that explores the nature of knowledge and its roles within formal politics as well as everyday decision making. Finally, the concept of 'risk governance' is introduced as a model of knowledge exchange and social learning in driving agricultural adaptation and change from formal politics to on-farm choices.

The Nature of Knowledge and Risk

Risk is a central concept in understanding the ways in which people interpret and experience an uncertain future change. Technical definitions of risk (UN/ISDR, 2002, Newhall and Hoblitt, 2002, Adams, 1995, Keylock, 1997) often objectify it as a defined negative future outcome (or set of outcomes) to which a probability of occurrence can be assigned. Underpinned by objectivistic understandings of knowledge production, reductionist approaches to risk, particularly in the research field of environmental hazards, has seen the concept bound up with notions of quantifiability and probability (Adams, 1995). As a consequence the task of risk assessment has been placed firmly in the 'objective' and 'rational' domain of the expert (scientist). The belief in an obtainable and quantifiable risk resulted in the 1990s in Stephen Bryers and America's National Academy of Sciences National Research Council (NRC) advocating the separating out of risk assessment and risk management, into distinct domains, the former of which should exclusively be the fact-finding task of scientists and the latter a political task based on the objective findings of the former (Shrader-Frechette, 1995, Millstone, 2007). Within such models, reductive-aggregative understandings of risk, in which simple metrics quantitatively capture the realities of social risk and offer a means of (usually linear and scalar) extrapolation for the purposes of risk management, take on a certain authority (Stirling and Scoones, 2009). The intuitive appeal of the political process of risk management being driven by an objective knowing of problems and risks, and an unbiased determination of 'what works' (Roberts, 2005) in response to them, is central to the popular discourse of 'evidence based policy' (EBP), which essentially promises the depoliticisation of policy. In many fields, such a concept continues to justify investments in scientific experimentation and research in the hope that better evidence will equal better policy.

This scientific ownership of risk as an object of study is built on the traditions of thinking within the Royal Society in Britain which, in 1983, published the report 'Risk Assessment', which made a fundamental distinction between 'objective risk', that which is known to 'experts', and 'perceived risk', that which is understood and anticipated by the lay person (Royal Society, 1983). 'Public understanding of science' (PUS) studies have become somewhat synonymous with the 'information-deficit' thinking that dominated its early endeavours (Irwin and Michael, 2003). Information deficit models were driven by a belief that observed differences between the 'perceptions' of lay public and the 'objective findings' of scientists were the product of a lack of understanding about, or lack of effective dissemination of, scientific processes and results within the wider society. This notion of perceived risk has been intellectualised and refined within a body of literature that focuses on the psychometrics of risk. Paul Slovic, amongst others, has published influential work on the properties of risk that influence the collective psychology of society and subsequently determines personal risk calculations and beliefs about its acceptability (Slovic, 1999, Slovic, 2000). This work effectively reinforced conventional distinctions between the rationality of objective science and the value-laden nature of non-expert opinion.

Based on the accepted logic of distinctions between 'expert' knowledge and 'non-expert' perceptions, the task of 'risk communication' became a clear priority of endeavours to manage risks, particularly in the UK[45]. The Bodmer report, published by the Royal Society in 1985, is a classic manifesto of an institution that wished to promote the better communication of 'expert' knowledge in order to educate an uninformed public about real risk (Horlick-Jones, 1998). This rationale is often evident within contemporary 'public engagement' or 'public sensitization' endeavours. However, endeavours to better educate the public have, in many cases, failed to impact significantly on the discrepancy between objective and perceived risks (Slovic, 1999, Stirling et al., 1999, Grove-White et al., 1997, Jasanoff, 1999). Owens (2000) points out that the flaws of the information-deficit model were clearly highlighted by the absence of any real social change resulting from efforts to communicate science:

> 'There could hardly be a clearer demonstration of the flaws in the information deficit model than the persistent refusal of the public to have their allegedly irrational conceptions of risk 'corrected' by providing them with information.' (Owens, 2000: 1142)

In practice, such findings struggle to undermine the information-deficit interpretation of science because of the self-justifying relationship that exists between assumptions about realism in science and a preference for autonomy within the scientific community. Beck (1992) argues that such separation essentially excludes reflexivity in the interactions between 'experts' and 'non-experts' over the assessment of risks and sets up a problematic dynamic that fails to acknowledge, or denies, that knowledge about the outcomes and probabilities can be incomplete and contested both within and beyond a community labelled as 'expert' (Stirling, 1999b). This critique has been extensively and effectively developed within a large body of literature on the social construction of knowledge (e.g. (Wynne, 1996, Shrader-Frechette, 1995, Irwin and Michael, 2003, Funtowicz and Ravetz, 1994).

Discontent with deterministic assumptions about the rationality of science led to the development of alternative theories to explain the continued disparity between scientific fact

[45] Vogel (1986) argues that this kind of technocracy was less pervasive in the USA

and public perception. This is a rich and diverse literature, from which three main arguments are drawn out and elaborated on here. These arguments can be summarised as follows:

- Scientific enquiry has limitations within a real world that is highly complex, and therefore uncertain and indeterminate.
- Knowledge is not produced independently of values, assumptions and framings that are shaped by social interactions within, and experiences of, the real world (including trust in industries and regulating bodies).
- For these reasons, a multiplicity of knowledge bases can produce legitimate and insightful knowledge about the realities of risk.

In relation to the first point, an ever-growing body of research on system dynamics from a variety of disciplines – farming systems research (Darnhofer et al., 2012, Collinson, 2000); socio-ecological systems (Folke, 2006, Young et al., 2006, Lambin and Meyfroidt, 2010); innovation systems (Freeman, 1995, Geels, 2004); climate systems (IPCC, 2007) – reveals the complex and chaotic dynamics of the real-world, characterised as it is by boundless, interacting systems that are non-linear and subject to unpredictable shocks (Scoones et al., 2007, Leach et al., 2010).

Work on climate modelling and projection is largely grounded in complex systems theory. Much like the global economy or ecosystems, the climate is conventionally conceptualised as a system comprised of numerous interacting components, with these interactions cumulatively contributing to interactions at increasingly large scales, eventually resulting in emergent whole system behaviour (Weaver, 1948), e.g. climate change.

Lorenz (1972), and others, realised the sensitivity of whole climate system behaviours to the interactions taking place at the scale of individual system components and thus recognised that climate systems and other complex systems were prone to chaotic behavioural responses. Chaos theory, which emerged as a field of mathematics, became closely associated with studies on system sensitivity and tipping points by Lorenz (1972) and was further popularised by, and more broadly applied in, the work of James Gleick (1987), influenced much of contemporary thinking about climate processes. This had implications for the way that the relationship between complexity and uncertainty is conceptualised and how the role of climate science is understood. As a consequence of this appreciation of complexity, the limitations of the bounded and controlled conditions of laboratory science and simulation models for translating into real world truths is increasingly recognised (most recently in the IPCC's Fifth Assessment Report). It is unsurprising that climate models, for example, continue to show divergent and contradictory projections of climatic change (see detailed discussion of this in Chapter Five).

The complexity of the real world is compounded by the reality that these complex physical systems similarly interact with unbounded social, political and economic systems. The interconnections between social meaning and the functioning of ecological systems, for example, have been effectively demonstrated by political ecologists (Geist and Lambin, 2002, Zimmerer and Bassett, 2003, Robbins, 2011, Forsyth, 2013) and resilience theorists (Folke, 2006, Folke et al., 2010), and a socio-ecological perspective highlights the need to frame ecological systems in relation to the meanings that stakeholders attach to its components and complex relationships. Beck (Beck, 1999, Beck, 1992) and others recognised that modern risks are created within and by societies. Climate change risks, for example, cannot be separated from the technological, industrial, and economic drivers of carbon emissions or the social and economic factors that both drive physical change and create vulnerability.

The significance of differences between the controlled environment of the laboratory and the complexity of the real-world became well established within risk literature. Beck (1992) explained how the British government's Pesticides Advisory Committee, in response to farmer concerns, made conclusions about the safety of herbicides based on toxicology studies conducted in controlled laboratory conditions, yet the reality known to farmers was that these conditions were unrealistic (because farmers do not have access to correct spraying equipment; protective clothing is adequate, or farmers could not afford to wait for ideal weather conditions). Similarly, in his study of sheep farming in the Lake District, Wynne (1996) shows how farmers became disillusioned by scientific reassurance about the effects of nuclear fall-out from Chernobyl, which were ignorant of local farming practices and based on bounded models of the Chernobyl fallout that ignored local scale variations in contamination dynamics and the contribution to contamination from Sellafield.

Within complex systems, quantifications of risk belie the reality that there are likely to be multiple potential outcomes that are undefined and unanticipated and that these probabilities are based on superficial boundaries placed around assumptions about system behaviour. Moreover, Stirling and Scoones (2009: 5) recognise a tendency for 'quantitative expressions of probability [to be treated] in a disembodied way, without reference to the associated contextual particularities and conditions'. As such, probabilities, and their founding assumptions, are scaled up from the experimental scale (e.g. the simulation models or the laboratory trial) to the spatial and temporal scales of the real world through linear extrapolations that further belie the complexity of the real world (Stirling and Scoones, 2009). Overall, this first key argument in criticism of conventional objectivism recognises the limitations of, and the inevitable knowledge gaps within, scientific inquiry when it comes to drawing conclusions about a real world that is highly complex and composed of unbounded and interacting dynamic systems.

The second key argument of the social constructivist turn pertains to the realisation that even within conventional science, knowledge is not objective or even socially and culturally vacuous, but rather is the product of sets of assumptions, methodological choices, values and framings. These are often not explicitly acknowledged, but may be institutionalised and embedded within scientific protocols to the extent that they reflect common practice rather than conscious decisions (Gibbons et al., 1994, Ziman, 1996) and in some cases may be traced back to political (and financial) motivations for producing evidence in support of particular narratives (Jasanoff, 1995, Newell, 2002). A large body of literature has emerged that highlights the value-judgements and subjective decision making involved in framing 'scientific problems', particularly those which presuppose societal objectives; selecting methodological approaches; and interpreting results (Hinchliffe, 2001, Shrader-Frechette, 1995):

> 'Although science, as such, does not always have consequences for public welfare and hence does not always involve judgments about ethical values, no science can avoid judgments about methodological values. Collecting and manipulating data, for example, requires goals and hypotheses that are methodological values. Without these goals and hypotheses, scientists would not have a criterion for which data and models were relevant in a particular situation, and which were not. Adjudicating disputes about which scientific methods or models to use thus ultimately requires an appeal to methodological values. Hence, because risk assessment involves uncertainty and applications of science, it requires value judgments.' (Shrader-Frechette, 1995: 118-119)

Studies conducted in the 1990s demonstrated how the institutional norms that govern the process of knowledge production (within a given institution) are socially constructed through the practices, habits and discussions of those that set out procedural protocols (Wynne, 1996, Ziman, 1996, Gibbons et al., 1994). Beck (1999) argues that such norms can effectively reproduce themselves by legitimizing the 'evidence' that they generate and limiting alternative approaches and framings:

> '... neglect of the cultural/hermeneutic character of modern scientific knowledge itself, seriously constrains the imagination of new forms of order and of how their social legitimation may be better founded.' (Wynne, 1996: 45)

An example of an institutionalised hermeneutic is evident in relation to the concept of 'substantial equivalence' as a criterion on which to justify regulating genetically modified foods in the same way as their conventional food equivalent, if they can demonstrate the same characteristics (Millstone et al., 1999). With no standard definition of what substantial equivalence is and how it is measured, the concept has been institutionalised in different ways such that the determination of substantial equivalence depends as much on the norms of the institution, in which the judgement is made, as on the properties of the food product[46]. Determining substantial equivalence on the grounds of metabolic profiling (as is done by the US Food and Drug Administration) and subsequently presenting food to the consumer as being identical, essentially denies alternative (and no less rational) understandings of equivalence (i.e. those of the consumer, which might be based on appearance, origin, inputs, etc.). In this case, and others, institutional norms and assumptions effectively reinforce the divisions of knowledge (i.e. 'expert' and 'lay') that were discussed earlier and it becomes apparent how certain social understandings of risk become institutionally excluded from risk analysis.

Wynne (1996) recognised that there was a normative conflict between the knowledge systems of farmers and scientists, whereby the former was based on an experience of uncertainty and adaptability whilst in the latter a culture of prediction and control underpinned the scientific endeavour. It is important to recognise that these are not just differences between science and society, but that different framings and norms exist within the scientific community and similarly can account for the discrepancies within science. Stirling and Mayer (2001) show, for example, how academics and experts from the food and agricultural industry come to very different, but nevertheless evidence-based, conclusions about the relative merits of alternative agricultural strategies, as a result of their different framings of a multiplicity of issues (Goffman, 1974, Stirling and Mayer, 2001, Stirling, 1997) that are both reflected in, and a product of, different knowledge cultures, different methodological choices and assumptions, different analytical interpretations of the data. Van Zwanenberg and Millstone (2000), analysing the use of evidence within agrochemical toxicology risk assessment in the UK and US, argue further that institutionalised assessments and methods may have degrees of epistemological robustness. Their realist approach to evaluating different knowledge claims is an important departure from the complete subjectivism within constructivist theory; this point is returned to shortly.

[46] Kuiper (2001) gives an excellent overview of how substantial equivalence is measured by different institutions

The third important argument to emerge from social constructivist literature comes from a recognition that when a complex reality is subject to multiple framings there are alternative knowledges, and alternative systems of legitimizing knowledge that offer important insights into the realities of risk. The contextualised knowledge of 'non-experts', developed through real experience of societal behaviour and values, is an important source of information which may be additional or even contradicting of 'expert' knowledges.

Wynne's (1996) paper not only highlighted the flawed assumptions of scientists and the value-judgements and politics that underpinned expert findings, but also demonstrated the value of the contextualised and experiential knowledges of the 'lay' farmers. Particularly in relation to complex problems that have social implications, even where 'experts' may have legitimate claim to having the best available evidence at their disposal, they do not have a monopoly over the valid interpretations and framings of the problem or potential solutions (Fischhoff et al., 1982, Owens, 2000). An appreciation of the value of, and even moral obligation towards, 'non-expert' knowledges has directly challenged the information-deficit thinking that dominated in the 1980s. The major difference between the Royal Society's 'Risk Analysis, Perception and Management' paper (Royal Society, 1992) and their 'Science and Society' programme, which ran a decade later, is a clear focus on mutuality in the exchange of knowledge between 'scientists, the public and other groups' (note that scientists have become just one interest group no longer empowered by the label of 'expert' over all other 'non-experts')(Royal Society, 2004). This shift is indicative of the ways in which academics began to deconstruct the barriers between science and society:

> 'Once one introduces the idea that scientific expert knowledge itself embodies a particular culture – that is, it disseminates and imposes particular and problematic normative versions of the human and the social – then this fundamental divide is no longer tenable... To relegate the public to the role and identity given in the dichotomous conceptualisations of expert and public... and to relegate scientific expertise to the associated condition of supposed cultural- and meaning-neutrality, is to commit society to further blind polarisation in the continuing transformations of modernity.' (Wynne, 1996: 75)

> 'Laboratory toxicologists may, for example, be insensitive to behavioural effects experienced in the field; designers may not see flaws that are apparent to operators; theoreticians may tend to forget the simplifying assumptions underlying their models. Even when the experts have a (near) monopoly on the best available facts of a matter, they need not have a monopoly on the set of possibly valid perspectives, particularly with problems having complex social ramifications or involving the interaction of diverse systems. In such situations 'the more the merrier' may be more appropriate than 'too many cooks spoil the broth'' (Fischhoff et al., 1982: 253)

This constructivist turn has been reflected in attempts to reconceptualise EBP and move it away from its objectivist roots. Pawson's (2002) slightly misleadingly-labelled 'realist synthesis' (which refers to the bringing together of multiple realities) argues that evidence includes not only systematic scientific research, but also knowledge gained through experiences, management practice and processes of reflexive social learning (Pawson, 2002, Sanderson, 2002, Head, 2008). The result is that EBP gains new legitimacy as a more contextualised and reflexive approach, attempting to determine 'what works for whom in what circumstances' (Pawson, 2002: 342).

Although, social constructivist arguments have effectively challenged conventional understandings of 'objective science' and 'subjective perceptions' and when we talk of 'knowledge' we are no longer limited to equating this with scientific truths, translating social constructivism theory into policy practice, or applying it within empirical research, is difficult. In addition, there is no clear consensus about the roles of knowledge, communication, and trust in creating and reducing risks (or risk perceptions). Taken to its logical conclusion, constructivist arguments that recognise the subjectivity of all knowledge endeavours are contradicted by a pragmatic need to place conditions of legitimacy on different knowledges. According to Louise Antony's bias paradox, which has become a classic thesis of feminist scholarship, if nobody is objective, then nobody is in a position to identify bias within anyone else (Antony, 1993). This idea is both practically and morally problematic, and has been addressed within social constructivist theory by those advancing epistemological realism as an alternative approach to complete subjectivism. Stirling and Scoones (2009), for example, point out that 'no matter what variety of framings might be possible, a range of interpretations will typically remain just plain wrong' (p.7). Van Zwanenberg and Millstone's (2000) findings justified an approach that went against the grain of 'most sociological analyses of risk assessment… [which are] agnostic when it comes to what should or does count as reliable knowledge' (p. 260) and instead presupposed that 'some risk assessments are far more robust and better constructed than others' (P. 260). They further argue that sociologists can play an important role in critically analysing knowledge claims on the basis of understandings of their construction and robustness. In the following section, a framework for conducting such analysis and systematically deconstructing knowledge claims is outlined.

Understanding Incomplete Knowledge

Replacing a linear interpretation of knowledge gaps as a way of interpreting differences between the predictions of experts and publics, or between experiments and the real world, with a vocabulary for interpreting the multi-faceted nature of incomplete knowledge can offer a conceptual framework that is compatible with a more realist approach to unpacking knowledge and analysing its robustness and legitimacy (Yearley, 2005). From recognition that both outcomes and probabilities can be problematic and contested, Stirling (1999) outlines a schematic description of incomplete knowledge, which usefully distinguishes that which results from alternative framings and values and that which is reducible through systematic scientific enquiry. Figure 4 offers four categorisations and explains how each relates to the extent to which knowledge about outcomes and probabilities is problematic.

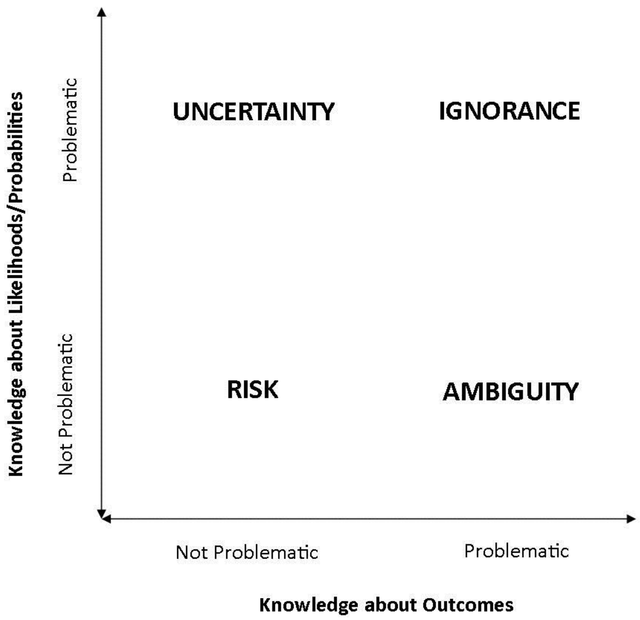

Figure 4 Schematic representation of incomplete knowledge. Reproduced from Stirling (1999)

Within this schema, ‘risk’ is considered as a particular condition of incomplete knowledge in which knowledge about potential negative outcomes and the likelihood that these outcome will materialise are understood as relatively unproblematic. Where experience and reliable scientific models produce accurate and largely uncontested knowledge, with regards to both outcomes and probabilities, there can be reasonable confidence in the quantification of the future through simple objective tools such as risk assessments or cost benefit analysis (Stirling and Scoones, 2009). In such circumstances, well-established reductive-aggregative approaches are appropriate and applicable. However, social constructivist critiques suggest that such conditions are rarely representative of knowledge gaps, around which there may be potential problems associated with the definition of outcomes, probabilities or both, and these scenarios give rise to three alternative descriptions of incomplete knowledge: ignorance, uncertainty, and ambiguity.

Uncertainty pertains to that component of incomplete knowledge that is characterised by a confident knowing of the potential outcomes of a situation without the tools and information necessary to make confident predictions of their relative likelihoods. In climate modelling, for example, projections of the future are based on the input of different emissions scenarios, but because of the complexity of political, economic and social factors that drive emissions it is not possible to assign probabilities to these various scenarios (this is discussed in more detail in Chapter Five). As a result, judgements about responses may come to alternative but equally plausible conclusions and so it is perhaps more appropriate to plan for variability, within the bounds of the known potential outcomes. A variety of tools that capture this bounded variability, such as scenario analysis (Moss et al., 2010, Patel et al., 2007, Kok et al., 2006, Peterson et al., 2003) as well as decision making criteria such as 'precaution' (Kriebel et al., 2001, Tickner, 2003) or 'no regrets' (Heltberg et al., 2009), are more appropriate than reductive-aggregative approaches of risk assessment under conditions of uncertainty.

Ignorance describes a situation in which knowledge about both outcomes and their probabilities is problematic. As such, potential outcomes may not just be contested (as in ambiguity) or have unknown probabilities of occurrence (as in uncertainty), but rather these outcomes themselves are unknown and even unknowable (Stirling et al., 1999, Stirling, 1999a). Stirling and Scoones (2009) point to the depletion of stratospheric ozone as a consequence of the use of halocarbons, as an outcome that was completely unexpected because it simply had not factored into anybody's frame of risk assessment (Farman, 2001). Amongst concerns about the cross-pollination effects of GM crops is that the future consequences of this process are unknowable (See Chapter Eight). Ignorance, therefore describes that gap in knowledge that results from the unexplained and may relate to potential impacts which are not yet identified (let alone ascribed a probability of occurrence) or observed dynamics for which there are not yet any tested theories. Whilst ignorance offers an antithesis to the basis of reductive-aggregative risk assessment approaches, it presents a real need for systematic, interdisciplinary, and 'basic' science that aims at real world observation and explanation (Stirling and Scoones, 2009, Yearley, 2005). It is through a reflexive endeavour that challenges the conventions of science that this kind of interdisciplinary science can best make observations of the unobserved and build and test theories about the unexplained in order to reduce ignorance (Giddens, 1990, Wynne, 1996, Lash and Wynne, 1992, Lash et al., 1996, Beck, 1992). In terms of policy implications, recognition of ignorance may be reflected in a preference for reversible, flexible, diverse and iterative approaches and instruments (Stirling, 2008).

Ambiguity refers to the condition of incomplete knowledge in which it is the identification of outcomes themselves (even those that have already taken place), as opposed to their probabilities, that is contested, or at least contestable. As such, ambiguity reflects the idea that alternative knowledges are intrinsically tied to (or constructed on the basis of) alternative framings of issues and realities (Stirling et al., 1999, Stirling, 2003, Leach et al., 2010, van Zwanenberg and Millstone, 2000). There may be dispute not over the relative likelihoods of a set of bounded outcomes, but rather over the actual positioning of those boundaries. In the case of crop breeding, for example, there may be multiple alternative criteria on which to base an evaluation of the efficacy of a project or product (this is elaborated on in Chapter Seven) and within technology regulation, different actors may subscribe to different framings of both the object and the aim of regulation (see Chapter Eight). Reflecting the second key argument of social constructivism described above, under conditions of ambiguity, different evaluations outcomes may result from different perspectives, values and framings, about which it may not be possible to make judgements about legitimacy or (following Antony's bias paradox) about which no one may claim the authority to judge legitimacy. Capturing multiple values, epistemologies and ontologies (Leach et al, 2005) for the purposes of policy making, action, or intervention is difficult, but tools such as 'multi-criteria mapping' (Stirling and Mayer, 2001) offer a systematic approach to inform and be combined with less structured qualitative approaches, such as discourse analysis (Van Dijk, 1993, Gee, 2013, Fairclough et al., 2011, Dryzek, 1997), that allow for the subtle and expression and identification of embedded values and narratives.

These conditions of incomplete knowledge are themselves constructs that may be differently perceived as applicable to any given situation by different people, and they are not mutually exclusive. Knowledge about a particular system could be interpreted as being both uncertain and ambiguous if, for example there are alternative legitimate theories about system dynamics and inputs, each of which is associated with probabilistically-unknown outcomes. In fact the labelling of incomplete knowledge as any one of these conditions is inevitably political. Just as ignorance might be invoked as an (almost) indisputable argument for closing down certain (usually technological) narratives, so too might actors attempt to 'close down to risk' (Leach et al., 2010) as a way of justifying 'evidence-based' approaches to policy-making that ultimately privilege the knowledge (and framings) of particular 'experts' and interest groups and exclude others (this is discussed further below).

Cartwright et al. (2009) argue that EBP requires a 'practicable theory of evidence' that clearly explains what constitutes evidence (and what does not), the legitimacy of alternative sources of evidence in speaking to policy, and how a hypothesis should be evaluated in light of alternative evidences (Cartwright et al., 2009). The insights of critical studies of the nature of knowledge suggest that such a theory should incorporate an understanding of the existence of incomplete knowledge and value-judgements. This Stirling schema provides a framework on which to base such a theory of evidence, and it is utilised and referred to throughout the research presented in this thesis in order to unpack these questions about what evidence (or knowledge) is, where it comes from, and how it is differently legitimised, interpreted and utilised, in relation to the future of maize agriculture in Kenya. Within the following chapters, this schema of incomplete knowledge is adopted in an attempt to reveal the assumptions, values, cultures and politics of narratives within the four case studies of the research.

Whose (Incomplete) Knowledge Counts?

There are a number of settings in which narratives of agricultural change are constructed, negotiated and realised. This is a process that is seen most formally within policy debates and government agenda setting, but the convergence and divergence of different narratives and visions of the future similarly take place in the management of farms, the writing and implementation of research and development project proposals, and in the running of experimentation sites and laboratories, to name just a few. These multifaceted and multi-sited sets of decision making, of different degrees of formality, are collectively described here as the governance of agricultural change:

> 'In both intentional and less intended ways, governance shapes how scientific and technological processes are directed, how environmental and health issues are defined and addressed, and how social consequences become distributed. They shape – and are shaped by - the interactions between people, technology and environment, and how these dynamics unfold over time…. In short, to understand how and why social-technological-ecological dynamics unfold in particular ways, and their implications for sustainability, poverty reduction and social justice, then we need to understand the governance processes involved.' (Leach et al., 2007)

Beck's (1992) risk society concept, recognises that people and societies are not just knowledgeable about technological and environmental risks, but are inextricably embedded in both the creation and experience of these risks, and transformative adaptation scholars argue that through learning, experience, reflection and information, individuals are capable not just of reacting to change, but of implementing actions and strategies that pre-emptively build the resilience of socio-ecological systems (Osbahr, 2007, Tschakert and Dietrich, 2010, O'Brien, 2012, Folke et al., 2010, Crane et al., 2011). Therefore, there are a variety of agencies that co-exist in relation to agricultural change.

The regulation of GMOs is one example of the governance of agricultural change that is focused on in this research and it provides a good example of how this governance is determined by the negotiation and contestation of narratives. In reference particularly to the context of formal policy making, Emery Roe (1994: 35) recognises that 'one of the ways in which practitioners, bureaucrats, and policy makers articulate and make sense of... uncertainty is to tell scenarios and arguments that simplify or complexify that reality'. Although this is represented in language, it is more than just a means of communication, it is an organisation of ideas, understandings and values that 'underwrite and stabilize assumptions for policymaking' (Roe, 1994: 32). Hajer recognised that the discourses that hold groups together are amenable to change, through debate and social learning, and that whilst groups might be defined by the discourse that holds them together, they are not permanent; just as discourses might alter subtly over time, so too might individuals or groups shift to identifying themselves with alternative discourses (Schmidt and Radaelli, 2004, Bulkeley, 2000, Hajer, 1995). According to Roe (1994) acceptable metanarratives, which become the foundation of policies, are the result of a resolution between conventional narrative and its counter narratives.

Given the existence of multiple agencies and growing emphasis on the participation of 'non-expert' knowledges in research, programme planning, and policy, understanding the mechanisms of narrative contestation and resolution involves thinking about relationships between different knowledges and different actors. As has been done in a body of critical commentary on participatory development, there is a need to ask whose knowledge counts and, ultimately, whose wins out and why, within the process of governance. Drawing on political theory, but recognising its applicability to a broader process of governance beyond formal policy making, the following section provides a review of mechanisms by which narratives emerge as dominant within the governance of agricultural change, and looks specifically at the roles of power, knowledge, and learning.

Politics, Power, and Learning

Presented below are three basic mechanisms of social change from which a dominant narrative either does or does not emerge and in which knowledge and evidence plays important, but distinct, roles: coercion and closing down alternatives; learning and cognitive change; and resistance.

Although it might seem intuitive to suggest that it is the narrative with the most power that will ultimately prevail, such suggestions inevitably contain inherent assumptions about: what power is, who holds it, and how it is exercised. Political theorists have been exploring and advancing theories about the role and location of power in processes of change since the 1960s, and much of the early literature continues to offer important insight. Elitist and pluralist theories disagree about the structural nature and predictability of power relationships. Within elitist theory, power is understood as a personal or institutional characteristic such that certain actors are understood as inherently and predictably powerful. Such a description is often applied to the way that large and wealthy institutions and corporations are able to shape agendas. In relation to the case studies explored in this thesis, the CGIAR, Bill and Melinda Gates Foundation, or Monsanto, are all actors that are often characterised as powerful elites. However, pluralist theories argue that it is the exercising of power that is important and, as such, power might be held by a whole range of actors and might be semi-permanent or temporary, tied to certain issues and facilitating temporary coalitions of interested groups. This is evident for example in the way that power shifts around key moments in the GM debate (see Chapter Eight).

Within pluralist theories, power is often associated with participation, however, from the work of Blowers (1980), Bachrach and Baratz (1962) and Lukes (1974), increasing attention has been paid to the more subtle ways in which power is exercised. Bachrach and Baratz's concept of the 'mobilization of bias', explains how power is exerted in the reinforcement of institutional practice of social and political values and norms that excludes certain issues or alternative framings of issues from the agenda. They describe this restriction of the agenda as the power of non-decision making (Bachrach and Baratz, 1963).

Knowledge and power interact in multiple ways in the shaping of social and political change. Flyvbjerg (1998), drawing on the work of Nietzsche, postulated that power and rationality were inversely related, and his work has argued that when there is a strong skew in the power held by political actors, those that are most powerful win out either without the need to justify their arguments with reference to evidence or because they can manipulate evidence without contestation. Pellizzoni (2001) recognized that discourses may have the power to eliminate others from debate on the basis of their dominance and superiority, in this case the power may lie at some point between those communicating the discourse and the discourse itself. Leach et al (2010) recognise that power may be exercised in the denial of knowledge gaps and the assertion that a particular narrative reflects an objective reading of evidence. Based on the classification of incomplete knowledge described above, this often manifests as a denial of ambiguity, ignorance and even uncertainty, which has been described as 'closing down to risk' (Leach et al., 2010: 79). In such situations, distinguishing the power of the narrative from the power of its advocates may become difficult.

Dryzek (2000) and others have recognised that social change can result from the deliberative negotiation of perspectives. The idea is that the arguments have agency of their own, and that individuals, groups, discourse coaliations, might change their judgements and values on the basis of interactions. There is an extent to which the success of particular narratives will depend on what Pellizoni (2001) describes as their 'internal' power. Within this model of change, knowledge can be conceptualised not just as playing a strategic role (e.g. a device invoked within political power plays), but also a substantive one that can speak independently to 'human reason' (Schön and Rein, 1994: 37), and contribute to a discovery of the 'best argument' (Habermas, 1983 cited by Pellizzoni, 2001) through deliberation and learning. From this perspective, policy making is not simply a process of 'sheer powering' (Radaelli, 1995: 164), but is, at least in part, a 'search for intelligible solutions' (Weale 1992, 222). Dryzek (2000) describes deliberation as:

> 'A social process [that] is distinguished from other kinds of communication in that deliberators are amenable to changing their judgements, preferences, and views during the course of their interactions, which involve persuasion rather than coercion, manipulation or deception.' (p.1)

Of course, delibration is rarely independent of the kind of exercises of power identified above, but it is most effective when these power dynamics do not dominate interactions and therefore negate the deliberative process. Dryzek (2000) argues that:

> 'A defensible theory of deliberative democracy must be critical in its orientation to established power structures, including those that operate beneath the constitutional surface of the liberal state, and so insurgent in relation to established institutions.' (p.2)

In an attempt to unearth and reduce the influence of power within deliberations, a large amount of research has looked at the way in which knowledge is communicated across differences (Fischer, 2000), and attempted to establish models for more inclusive and participatory processes of policy making (Jasanoff, 2003, Renn and Schweizer, 2009, Leach et al., 2005); some of these models are introduced later in this chapter.

In spite of coercion, closing down, and learning, it is important to recognize that stand-offs between perspectives can persist, either because there is no bridge across which knowledges can be communicated, or because the assumptions that underpin perspectives continue to reinforce and justify those perspectives:

> 'Policy narratives often resist change or modification even in the presence of contradictory empirical data because their tightly storied characterisations, metaphors, and emplotments continue to underwrite and stabilise assumptions.' (Roe, 1994: 2)

This is a condition that Thompson and Warburton (1985) describes as 'contradictory certainties', without acknowledgement of uncertainty within alternative narratives, there is, in essence, nothing to be negotiated. As a result, social change does not happen and groups continue to stand in firm resistance to each other.

Knowledge plays a complicated role within governance processes which often display elements of all three of the mechanisms outlined above. Whilst the communication of knowledge can be an important driver of cognitive change, power is often exercised in the determination of what knowledge is created, whose knowledges are included and excluded, and how that knowledge becomes interpreted within communication. Similarly resistance often involves a refusal to accept the legitimacy of certain knowledges. To be able to support a narrative with reference to knowledge or evidence becomes an important means of legitimacy and a means of delegitimizing alternative narratives. Knowledge and politics are inextricably linked and, as such, deliberations and knowledge exchanges may be entered into from a critical and even sceptical perspective. As a result, and discussed in the following section, social relationships and trust play an important role in shaping the interactions involved in the governance of agricultural change.

Social Relationships and Risk

Trust, knowledge claims, and risk are intrinsically related in often surprising ways. Millstone and van Zwanenberg (2000) make reference to a study conducted by Monsanto in the UK in 1998, which suggested that levels of public confidence in the safety of GM foods was significantly lower amongst those that had been informed that the British government itself was satisfied about its safety. This finding indicates a distrust of government claims to the extent that it alters individuals own risk perceptions, which appear to be both reactionary to external information and, as discussed below, socially and historically embedded.

The concept of social interactions and solidarities reinforcing cultural barriers and constructions of risk has been developed in literature on the social amplification of risk (Renn and Levine, 1991, Renn et al., 1992, Pidgeon et al., 2003, Kasperson et al., 1988, Kasperson et al., 1992). This literature recognises that development of social and communicative barriers can incubate certain perspectives, perceptions of risk, and distrust, which effectively reinforce the social norms within these barriers (Douglas and Wildavsky, 1982, Lima and Castro, 2005). This scenario is described here as the 'internalisation of knowledge', reflecting an insular approach to risk management that is distrusting or sceptical of external knowledges, and it represents a significant challenge for achieving deliberative governance that seeks to drawn on knowledge from, and communicate across, these social and cultural barriers.

Paul Slovic and others have shown how a distrust of governments and technologies is amplified through insulated social interactions and a lack of engagement with 'outsiders' (which may itself be the result of distrust) (Slovic, 1999, Pidgeon et al., 2003, Renn et al., 1992, Renn and Levine, 1991, Lomax, 2000, Priest, 2001). Frewer (1999) has suggested that this level of distrust is greatest in those regulating 'new' technologies and can be amplified through limited cross-barrier transparency, i.e. where communication between scientists and the public is largely through sensationalist media (Petts et al., 2001, Frewer et al., 2002, Pidgeon et al., 2003). In the same way that institutions reinforce their legitimacy through institutional norms, so do social groups reinforce cultural barriers through social norms (e.g. levels of risk acceptability and trust in institutions are mutually reinforcing and legitimised through conversations, social behaviours, consumer choices, protests, media reports etc.). Lash and Wynne (1992) argue, along with a large body of more recent sociology literature (Hinchliffe, 2001, Irwin and Michael, 2003, Irwin, 2001, Stirling, 2003, Finucane and Holup, 2005, Pellizzoni, 2010), that it is in these barriers and social and cultural practices that risks are socially constructed:

> 'Physical risks are always created and affected in social systems, for example by organisations and institutions which are supposed to manage and control the risky activity... The magnitude of the physical risks is therefore a direct function of the quality of social relations and processes.' (Lash and Wynne, 1992: 4)

A number of studies have demonstrated the close correlation between risk acceptability and levels of trust in risk regulating institutions (Flynn et al., 1992, Slovic, 1993, Siegrist and Cvetkovich, 2000, Bord and O'Connor, 1992). Whilst the correlation between trust and risk perception is widely acknowledged, the nature of this relationship and the direction of causality has been questioned (Eiser et al., 2002, Poortinga and Pidgeon, 2005). A 'causal chain' (Eiser et al., 2002), in which levels of trust determine risk perceptions, and therefore acceptability, has been commonly accepted, but there is some evidence that an 'associationist view of trust', in which both trust and risk perceptions are both the product of more general values and opinions about an activity (Eiser et al., 2002) – their 'affective evaluation' of it (Poortinga and Pidgeon, 2005) – may be more accurate. Finucane et al. (2000) argue that trust is inextricably captured within a broader judgement about risk that they have called the 'affect heuristic'.

A large body of literature, led by the contributions of Paul Slovic and colleagues, which draws on empirical data that is predominantly from the United States and Europe, has shown that perceptions of risk and distrust of industries and regulating bodies is particularly heightened around modern technologies, such as nuclear power, and bio- and nano-technologies (Poortinga and Pidgeon, 2005, Slovic, 2000, Slovic, 1993). However, there are distinct national differences in risk perceptions, which have been attributed at least in part to different levels of trust in national governments (Slovic, 1993), and very few empirical studies of risk perception and trust have been conducted in the global south.

In his work on reflexive modernity, Giddens (1994) argues that, in the context of the modern risk society, 'active trust' will be essential for maintaining social cohesion and countering and responding to risk. In an extension of this theory, it may also be said that active trust will be essential for achieving good governance; a concept which is discussed further in the following section.

Risk Governance and the Role of Knowledge Brokers

The trajectory of debates in risk studies over the past two decades has led, if nowhere else, to a realisation that 'risk and governance are not separate concepts, but belong to spheres of investigation and practical interest that are strictly intertwined' (De Marchi, 2003: 171). The rise of social constructivism and the challenges to the conventional monopoly of 'experts' over the definition and measurement of risk, has resulted in international agreement about the need for public participation in both knowledge production and policy design (e.g. Cartagena Protocol on Biosafety). The concept of 'risk governance' emerges from recognition of the limitations of knowledges and the value of including those conventionally categorised as non-expert for both improving the quality of evidences and the acceptability of policies and practices (De Marchi, 2003, Renn and Schweizer, 2009, Sellke and Renn, 2010). It comes from risk studies and political science scholarship, and is based on the idea of deliberative politics as a way of not only giving a voice to, but also integrating, multiple values, normative positions, and constructions of risk.

This research considers governance in a number of settings and makes a case for the value of knowledge exchanges and learning in improving operations within farming systems and international agricultural research alike. Structures of governance range from the mechanisms and institutions of government to the informal structures of social groups, but all are bounded and define 'insiders' and 'outsiders'. Here, the concept of deliberative governance (a term that is adopted in place of 'risk governance' in this research to correspond more closely with the multifaceted nature of incomplete knowledge that is negotiated within governance) is used to represent the participation of farmers in international agricultural research, the input of agricultural impact models into on-farm decision making, and even the participation of technology developers within agricultural policy making, as well as a whole host of other combinations of participation and knowledge exchange.

Stirling (2008) argues that rather than determining the winning and losing narratives, deliberative approaches are about achieving inclusiveness in a process of 'opening up' to multiple perspectives and social learning. Black (Black, 1998, Black, 2002) identifies the main challenge of regulation as fully integrating multiple perspectives or normative positions, rather than privileging one and marginalising the rest. She suggests that:

> 'Integration does not mean the replacement of a multitude of perspectives with the regulatory imposition of just one. Rather integration is the full recognition of different perspectives in the regulatory process' (Black, 1998: 622)

Risk governance has come to represent a popular umbrella term that covers a range of different models and frameworks that differently emphasize, and respond to the challenges of, knowledge exchange and communication. Black (1998) argues that these challenges are three-fold: structural (i.e. the challenge of establishing the infrastructure for communication between perspectives to happen in); communicative (i.e. the challenge of different people talking different languages – whether it be the language of law, of ethics, of health etc. – and being understood); and cognitive (i.e. the challenge of people bringing different conceptualisations of the issues to be addressed). These three dimensions are briefly elaborated on here.

Institutional rules and social norms alike determine the ability of actors to achieve meaningful participation in forums of governance (Cleaver, 2001). Sociological institutional analyses have revealed ways in which institutional rules, protocols, hierarchies and practices reinforce status quo governance (Leach et al., 2007, Smith, 2005) and Mosse (1994) notes that even within the application of participatory rural appraisals, the organisation of focus groups and a targeting of consensus can act to further marginalise or disempower certain actors (Cooke and Kothari, 2001). The structural challenge of integrating multiple perspectives, then, is about readdressing structures of exclusion and facilitating meaningful and full participation, this in turn, as sociological institutional literature has suggested, may involve exposing and challenging the power that certain actors hold to define structures (Leach et al., 1999, Stirling, 2008, Cleaver, 2001). Methods and languages of communication can be similarly exclusionary. Different professions and communities often have common languages that are inaccessible to those outside of them, and language barriers can be particularly significant between those groups conventionally categorised as ‘expert’ and ‘non-expert’; the written and highly technical language of expert knowledges may be inaccessible to those more accustomed to non-written and non-academic knowledges. The communicative challenge, therefore, is in offering legitimacy to the many languages of alternative knowledges and facilitating dialogue across them.

The cognitive challenge refers particularly to the acknowledgement of ambiguity and the opening up of governance to alternative framings of problems and solutions. It is in the initial framing of debates that certain perspectives can be legitimised or excluded, but in meeting the cognitive challenge, this framing must itself be participatory and inclusive of alternative knowledges. However, this of course has pragmatic implications, and may negate the goal of achieving ‘best policy’ in response to pressing issues, particularly if the nature of the issue is contested (Bulkeley and Mol, 2003, Stirling, 2008). Whilst it is possible for framings to be renegotiated through mechanisms of inclusive governance, where ‘contradictory certainties’ (Thompson and Warburton, 1985) emerge from alternative framings between which there is no middle ground, opening up to alternative framings may inevitably negate the achievement of consensus. As such, there are incompatibilities between meeting the cognitive challenge of participatory governance and maintaining its functional virtue.

The significance of these challenges is differently recognised within different models of governance, depending on the theories of risk and knowledge that underpin them. The following section describes emerging literature on risk governance, the models that have emerged within it, and the approaches and instruments for meeting the challenges of risk governance captured within them. Notable differences between these models reflect the different perspectives that their advocates have on the multi-faceted concept of risk (i.e. its constructed/objective nature, the role of trust and social relations, etc.) and different underlying rationales for risk governance.

Table 2 is adapted from Renn and Schweizer (2009) and describes six main conceptualisations of risk governance and related methods and instruments:

Table 2 **Six concepts of risk governance adapted from a table presented by Renn and Schweizer (2009)**

CONCEPT	THEORY OF KNOWLEDGE AND NARRATIVES	METHODS AND INSTRUMENTS
Functionalist	Local/indigenous/ and non-expert knowledges can fill knowledge gaps to create better evidence for deciding on best argument	Delphi method, workshops, inquiries, citizen advisory committees
Neo-liberal	A democratic decision over the best argument – between alternative knowledges – to choose best policy	Referendum, focus groups
Deliberative	Negotiation between alternative knowledges can facilitate social learning to collectively create the best argument	Discourse-oriented models, citizen forums, deliberative juries, participatory scenarios
Anthropological	Focus on underlying cultural biases and social relations as a way of understanding and addressing risks, and building trust	Participatory scenarios, citizen juries
Emancipatory	Empower marginalised knowledges in order to strengthen the adaptive capacities of the most vulnerable and facilitate marginalised narratives	Action group initiatives, community development groups, participatory scenarios
Post-Modern	Opening up to a plurality of knowledges allows for the maintenance of multiple narratives of change	Open forums, panel discussions, participatory scenarios

These concepts are not mutually exclusive, and models of risk governance are often based on hybridised theories of knowledge and narratives, and rationalised on the basis of more than one virtue (Sellke and Renn, 2010, Renn and Schweizer, 2009). However, competing models of risk governance reflect alternative ideas about the virtues of both the process and the outcome of bringing together multiple knowledges, their relative legitimacy, and the roles of alternative knowledges, communication, and trust in creating and reducing risks. Three of the resulting models are described and contrasted here: the 'analytic-deliberative' model; the 'post-modern' model; and the 'scientific citizenship' model.

The 'analytic-deliberative'[47] prototype is the most commonly referred to model of risk governance (Ackerman and Fishkin, 2004, Burgess et al., 2007, Renn and Schweizer, 2009, Sellke and Renn, 2010, Renn, 1999). Common methods of facilitating participation within this model are deliberative juries and workshops, the aim of which are to determine 'best' knowledge through information exchange and consensus building. Fundamental ideas about risk representing incomplete knowledge and the power of objective information to rationalise perspectives (almost akin to information-deficit theories) underpin the 'analytic-deliberative' model:

[47] Based on the National Research Council's model of democratic policy making (Stern and Fineberg, 1996)

> 'It does not make sense to replace technical expertise with vague public perceptions, nor is it justified to have the experts insert their own value judgements into what ought to be a democratic process' (Renn, 1999: 3053)

Renn and Schweizer (2009) suggest that the functional virtue of participatory risk governance is in achieving legitimacy and social acceptance of policies, and the function of communication and knowledge exchange is further understood by others as a way of building social resilience and reducing vulnerability (Sellke and Renn, 2010). In a sense, the analytic-deliberative model presupposes that communication is achievable, and does not dwell on the suggestion that cultural and social positions might create 'contradictory certainties' in risk perceptions or represent barriers to engagement (i.e. a trust gap), or even that risk itself might be produced within these cultural and social divides.

The analytic-deliberative model can be contrasted with the post-modern model of risk governance, which places less emphasis on pre-defined stakeholders or pre-framed discussions, but rather achieves participation through open (and often anonymous) discussion forums (Schmidt et al., 2008). The focus within such approaches is less on legitimizing information and building consensus, and more on acknowledging plural rationalities and the idea that risk is differently constructed within and across society. However, anonymous deliberation fora have been used informally, and are often established and moderated by campaign groups; as such they are often spaces for constructing a specific type of risk knowledge and reinforcing socio-cultural barriers[48].

The popularity of a 'scientific citizenship' discourse (Irwin, 2001, Davies and Wolf-Phillips, 2006, Leach et al., 2005, Weldon, 2004) reflects the growing emphasis placed on the value of societal ethics and citizen values in the process of knowledge generation. This is reflected in a model of risk governance that shares many of the traits of the analytic-deliberative model of risk governance, but places greater emphasis on society-led science, such that participants play a greater role in framing issues as well as discussing appropriate methods, scales of analysis and analysis criteria, and has been labelled the 'co-production of science' (Jasanoff, 2003, Jasanoff, 2004, Wynne, 2006)[49]. Advocates of this 'upstream' participatory science extol the virtues of knowledge exchange and social acceptance (as in the analytic-deliberative model), but also see it is as an opportunity for improving transparency, communication and trust across social groups (Wilsdon and Willis, 2004, Wynne, 2006).

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[48] See literature on the 'social amplification of risk' (Kasperson, *et al*., 1988; Renn *et al.*, 1992; Frewer *et al.*, 2002)
[49] See Ferrete and Pavone (2009) for two recent case studies of this model of risk governance

Different models focus differently on meeting the challenges of governance outlined by Black. Whilst the analytic-functionalist model pays little attention to the cognitive challenge of opening up to multiple framings, this is central to the rationale of the post-modern model. A scientific citizenship model focuses particularly on building trust through the revealing of incomplete knowledges and a transparent revealing of cultural biases (Bäckstrand, 2003, Jasanoff, 2003, Jasanoff, 2004, Irwin, 2001). Similarly, there is different thinking on whether the integration of multiple knowledges should be achieved through the seeking of consensus, or the opening up to and maintenance of multiple narratives of change, including those that are otherwise marginalised.

Within science policy studies there has been increasing interested in, and critical assessment of, the role played by knowledge brokers in facilitating the communication of knowledge across groups (Meyer, 2010, Pielke Jr, 2007, Sverrisson, 2001, Lomas, 2007, Berkes, 2009). A knowledge broker may be an institutional representative, a media and communications professional, an independent individual or organisation, or (increasingly) a trained academic researcher, that acts to translate information across communication and cognitive barriers (Meyer, 2010, Sverrisson, 2001). However, the terminology of 'brokering' suggests something more than the unidirectional communication of a message (such as takes place within public sensitization exercises or scientific journalism) or a transfer of technology (e.g. from one country to another), but rather speaks of a responsibility in both facilitating and participating in a multi-directional exchange of knowledge and a process of social learning (Berkes, 2009).

> 'On one hand, there is a translation of knowledge from one world to another. On the other hand, we see efforts to make knowledge socially, politically, and/or economically robust. So both the translation of knowledge and the translation of accountability/usability take place. The end result of these translations is the production of a new kind of knowledge—what we could call brokered knowledge. Brokered knowledge is knowledge made more robust, more accountable, more usable; knowledge that 'serves locally' at a given time; knowledge that has been de- and reassembled.' (Meyer, 2010: 123)

Within this process, the knowledges, assumptions, culture and bias of the knowledge broker inevitably plays a role in shaping the 'brokered knowledge'. Pielke's (2007) commentary on science policy, engages critically with the way that evidence and knowledge is framed and communicated through intermediaries, and he draws a distinction between the 'arbiter of science' (who responds directly to factual questions posed by the decision maker), the 'issue advocate' (who promotes a particular course of action); and the 'honest broker of policy options' (who attempts to open debate to all potential courses of action and reflects on the consequences and uncertainties of each without pushing for a particular outcome). As discussed above, it is not possible for any actor within a deliberative process to fully remove themselves from their own values and assumptions, but achieving dialogue across alternatives is dependent on the ability of actors to reflect on incompleteness within their own knowledge (Wynne, 1996, Giddens, 1994). It is in this reflection that an 'honest broker' of knowledge can play a particularly vital role.

Meyer (2010) recognises that knowledge brokering is currently limited to particular locations, such as the space between academia and societal groups, in which there is an intentional knowledge exchange effort and a developed infrastructure, however there are multiple exchanges in multiple settings in which brokering, whether it is conducted through a formalised process and designated brokers or it is simply embodied within participants' attitudes towards knowledge exchanges, could and does play an important role. Throughout this thesis, in looking at the opportunities and challenges of governing agricultural change, the role that different actors play as knowledge brokers will be given critical consideration.

Conclusion

A broad theoretical background for this research, which takes account of the multi-faceted nature of knowledge and rationalities and the multiple social and political mechanisms through which they are constructed, negotiated, and amplified, has been outlined above. It is argued that incomplete knowledge, evidence and assumptions are inextricably tied up with the political processes through which they both gain legitimacy and act to legitimize. Within and across the case studies of smallholder farming, climate-crop modelling, crop breeding, and technology regulation alike, this research maintains the themes of unpacking incomplete knowledge; critically reflecting on evidence bases; uncovering a politics of knowledge and evidence; and identifying opportunities for learning and knowledge brokering.

It is argued that in preparing for an uncertain future, acknowledging the incompleteness of knowledge and the value of multiple knowledges, as opposed to implementing adaptation strategies that are based on hegemonic assumptions, will be essential for achieving appropriate outcomes. In practice, this means finding ways for different actors – farmers, climate scientists, crop breeders, and technology regulators – to participate in new types of knowledge exchange; overcoming structural, communicative, cognitive, and trust barriers; and minimising the role of power in dictating the framings and operation of these knowledge exchange. These significant challenges will be revisited throughout the thesis.

The methodological approach of this research, described in the following chapter, draws on several of the methods and instruments included in table 2, and as such they are based on the principles of risk governance, they target both critical reflection on knowledge incompleteness and meaningful participation, and they attempt to overcome structural, communicative, and cognitive causes of exclusion. Consequently, the research itself aims to make a contribution to (honest) knowledge brokering.

Chapter Four: Methodology

A Multi-Sited and Institutional Ethnographic Approach

The central and sub-questions of this research require a methodological approach that is capable of: describing the multi-faceted contexts in which a variety of stakeholders in the future of Kenyan maize agriculture produce knowledge; observing social interactions and processes of knowledge production; and analysing narratives and their communication. The previous chapter outlined a conceptual framework for this analysis and mentioned some of the methodological instruments compatible with studying narratives and alternative knowledges and combining them within policy making. These tools placed emphasis on participatory engagement; a theme that is picked up in this chapter.

In order to trace the origins and nature of knowledge and narratives, observe processes of social construction, and analyse opportunities for knowledge exchange, learning, and governance, an approach of ethnographic observation was combined with key informant interviews and systematic literature reviews. Some participatory research (in stakeholder forums and focus groups) in which opportunities for knowledge exchange and social learning were created and observed was also conducted.

Different actors produce, exchange and act on knowledge differently, from the following of scientific protocols and the careful documentation of processes in scientific reports to the much more informal and even subconscious processes that farmers, for example, might find themselves engaged in from day to day. As such, research on different case studies involved different sources of data. In this chapter, the methodological approach of the research is explained and justified and the sites and methods of data collection are described. The approach taken to data analysis is also outlined in the chapter.

Methodological Approach

An ethnographic mapping of projects, institutions, and social groups was used throughout this research to observe, describe, and explain processes of knowledge production and exchange. Although ethnography has its limitations, particularly in terms of the reproducibility of research, the experiential and emic basis for its insight offers a means of interpreting processes at local and personal, familial, or institutional scales (Brewer, 2000, Agar, 1996, Geertz, 1994, Robben and Sluka, 2012). Briefly described here are two forms of ethnography that are simultaneously applied in this research. The first is multi-sited ethnography (Marcus, 1995), which relates to the following of linked, but contextualised, processes across geographically dispersed locations and groups. The second is institutional ethnography (Smith, 1987), in which the sites of ethnography are determined by the operations of an institution and the aim is to describe and explain how the identities, meanings and narratives of that institution become socially constructed.

Multi-sited ethnography has become a popular and broadly applied approach within anthropological studies that instead of focusing on contextualising an object within a broader world system, aims at understanding processes that operate across this system – following social, cultural, political, and even economic interconnections, interactions, and movements, across multiple sites, with a particular emphasis on understanding the role of these connections within broader constructions of meaning (Marcus, 1995, Marcus, 1999), without making deterministic assumptions about the dependencies of knowledges across sites and scales (Millstone, 1978). The emergence of this approach to ethnography simultaneously challenged the conventions of long-term, locally-embedded data collection methods and opened up both the research field and the application of ethnography to a broad range of subjects of study (Robben and Sluka, 2012). In multi-sited ethnographies, a depth of description may be sustained by drawing on multiple data-sources (e.g. combining conventional ethnographic observation with key informant interviews) and focusing on specific types of interaction or flow (e.g. knowledge exchanges) between sites (Robben and Sluka, 2012, Brewer, 2000). A multi-sited ethnography is particularly useful in addressing the questions of this research because of the interest in understating the ways that incomplete knowledges are communicated and how interactions with alternative knowledges shapes the meanings and narratives that emerge in a multitude of settings. However, the concept of multi-sited ethnography has received some criticism, with some authors pointing out that the language of being 'multi-sited' suggests a false holism that masks the inevitable reality that certain social relations are absent from study, and excluded on the basis of the researcher's own definitions (something that an ethnographic approach seeks to minimize) and selection of individual sites that are themselves part of a broader world system (Candea, 2007) or 'single geographically discontinuous site' (Hage, 2005) . As such, the distinction between a 'multi-sited' and conventional ethnography may be relatively arbitrary and, as Hage (2005) suggests, based on the researcher's own delusions of originality. Within this research, no grand claims to holism are made, but the concept of 'multi-sitedness' remains appropriate because of the distinct geographic and (as the research later finds) cognitive, communicative and structural separations that create sites that are not simply connected, but also disconnected (according to the constructs of research participants as well as the researcher). Moreover, following these connections and disconnections across such a diverse research field, even within multi-sited ethnographies, is rarely done and, as such, this research represents an interesting trial case for those debating over the appropriateness and limitations of applications of ethnography across multiple (or geographically discontinuous) sites.

An institutional ethnography approach was first utilised in studies of women's movements in North America (Smith, 1987), and began as a means of critiquing the 'ruling relations' that structure and suppress people's lives. It is an approach to studying the way in which 'texts' coordinate the actions and consciousness of individuals in the creation and maintenance of an institution (Smith, 1999), and is based on an observation, similar to that outlined in Maarten Hajer's (1997) theory of discourse coalitions, that instruments of social organisation are discursive and textual in nature (Smith, 1999; Myers, 2009). It is everyday lives that are often used as the point of entry in institutional ethnographies, the observation of which reveals the 'texts' through which the realities of individuals are constructed. Within institutional ethnography, 'texts' can be understood as 'verbal routines inscribed in organizations' (Fairhurst and Putnam, 2004: 8) and Myers (2009) explains that 'texts are those common bits of knowledge that inform and indirectly motivate individuals in regard to what to do, how to behave and how to interact' (p.13). Such text may be found in project and strategy documents and official communications, but also in official and unofficial verbal representations and informal discussions. Discursive construction is only instrumental when it is received, accepted, and eventually influences an action or decision, and so it is necessary to focus not just on an analysis of text, but on the process of 'experiencing' text. Institutional ethnographies often focus on the discourse analysis of policy documents, proposals, and organisational records (André-Bechely, 2005, Eastwood, 2005, Stooke and McKenzie, 2009, Grahame, 1998, Turner, 2001, Rankin, 2001). These are the building blocks of the construction process, and are necessarily combined with the observation of discourse and the development of understandings of social processes and dynamics that result in decisions and actions (Campbell, 1998).

A key robustness control within a methodological approach that is relatively fluid, often opportunistic, and requires the making of assumptions and value judgements, is the application of a critical self-reflection. Inevitably, within an ethnographic study, the researcher becomes a part of the research subject (Brewer, 2000, Robben and Sluka, 2012) and, in the case of this research a part of the knowledge exchange through which narratives are shaped. In terms of the validity of the research findings, it was important that I reflected on my own role in shaping the research site and subject, but more than this, in terms of integrity of the research framework and objectives, reflecting on my own ignorance, value judgements and assumptions was an important part of building trust and facilitating knowledge exchanges as explained in the previous chapter.

The methodological approach, then, is not simply about observation and explanation of processes of narrative construction, but it is about participation in them; both facilitating and reflecting on an involvement in knowledge exchanges. The participatory approach of this research is an important counterpart to the ethnographic aspect, because it presents opportunities for data collection that are focused on specific (and to some extent artificial) interactions, both within and between groups. Although the creation of focus groups and workshops is somewhat counter to the ethnographic ethos of studying the 'natural' order of contextualised processes, these artificial constructs can produce large volumes of data (that is nevertheless contextualised through the ethnographic findings), that can make this multi-sited research possible within the time limitations of PhD research.

The focus on narratives and the construction and legitimization of meanings within this research lends itself to the application of narrative analysis as an approach to analysing data. Meanings and narratives hold within them language that is key to the identification of the knowledges that underpin them (Fairclough, 2003, Johnstone, 2008) and the constructed nature and, particularly the politics of narratives is often evident in the continuities and contradictions of language across the narratives (Dryzek, 1997). As such, 'texts', which themselves embody meanings and narratives, are useful objects of analysis (Gee, 2013). Emery Roe (1994) has advanced the application of narrative analysis within studies of policy processes and debates, and focuses on connections and disconnections between main- and counter-narratives, and Jones and McBeth (2010) argue that such an approach should be systematic and structured around a classification of both narrative components and policy processes. These classifications, then, represent a language for coding textual data. In its application to this research, the conceptual framework described in the previous chapter provides useful classifications for thinking both about the nature of knowledge that underpins narratives (Stirling's schema of ignorance, uncertainty, ambiguity, and risk) and describing process of knowledge exchange and narrative interaction and change (coercion and closing down alternatives; learning and cognitive change; and resistance) and their barriers (structural, communicative, cognitive, distrust).

More information on the specific methods employed, data collected, and coding and analysis techniques, is provided in the remainder of this chapter which essentially tells the story of conducting the research.

Literature and Secondary Data Review and Actor Mapping

The research began with a mapping out of the research sites by identifying key actors and processes involved in the production of climate-crop models, smallholder maize farming, the breeding projects of the DTMA and WEMA, and Kenyan biosafety policy making. In each of the four cases, information from peer-reviewed literature, project reports, and, in the case of smallholder farming, from CCAFS village survey data, was compiled into flow-chart diagrams which roughly represented actor-networks for each of the case studies:

- In the case of climate-crop modelling, an outline of the main stages of the process was developed from a systematic literature review (details of this systematic review can be found in The Methodology Appendix) from which were identified six completed crop modelling projects, which have at least a partial focus on simulation of future maize yields in Kenya (including those that focus on multiple crops and/or wider geographic regions). The projects reviewed are summarised in The Methodology Appendix.
- In the case of smallholder farming, CCAFS village survey data[50] contained detailed information about the relationship between two case study villages, within the Districts of interest in this research (more information on this below), and this proved useful particularly in thinking about the scope of connections between farm systems and a broader network of actors, connections that became a key focus of the research in these sites.
- The material used for the initial background research on the DTMA and WEMA projects of crop breeding was online project documents (reports, briefs, updates) accessible through the project websites[51] (the Methodology Appendix details the material that was initially reviewed).
- In the case of biosafety policy, a review of literature was conducted; from which was revealed a small body of peer reviewed literature that documents and critically analysed policy processes around the establishment of the Biosafety Act and subsequent legislations (details of this review are also available in the Methodology Appendix)

These initial flow chart diagrams (presented in figures 5, 6, 7, & 8) were iteratively adapted and modified throughout the research process and were useful for establishing the boundaries of the research sites and identifying key informants, interactions, and points of entry for the primary

[50] CCAFS baseline survey data is publically available and can be accessed at: http://ccafs.cgiar.org/resources/baseline-surveys
[51] dtma.cimmyt.org; wema.aatf-africa.org

data collection. The flow charts contain a large amount of varied information and represent an initial attempt at positioning organisations, actors, knowledges, and processes, as well as timelines of events and organisational histories. In the case of climate-crop modelling (figure 5) the central flow chart follows the production of a model output and includes different data sources and positions different organisations and models at appropriate points along the chain. In the case of smallholder farming (figure 6) the central flow chart follows annual maize farming activity and identifies some of the organisations, individuals, and information sources that a farmer may come into contact with throughout the process. Relating to the WEMA project a flow chart (figure 7) was produced that follows the project activity across the course of the development, trialling, and dissemination of a new technology and it identifies key actors, WEMA project teams, and locations at points across the chain. The final flow chart (figure 8) has at its centre a timeline of biosafety regulatory development, with key moments in national and international policy and key organisations and policy actors identified at different stages; arrows indicate where actors influenced policy or where policies created new agencies and regulatory bodies. The initial drawing of these maps and the making of initial contact with informants in the research sites was done over a period of three months.

From this starting point, I began an iterative and cyclical endeavour of making contact with key actors, conducting interviews, visiting locations, discovering new elements of these networked processes and building a richer and more nuanced understanding of them. It was an endeavour that took me firstly to the Meteorological Office in Exeter (as well as meetings with other UK-based ‘experts’) and then to the research centres, corporate offices and governmental buildings of Nairobi and beyond.

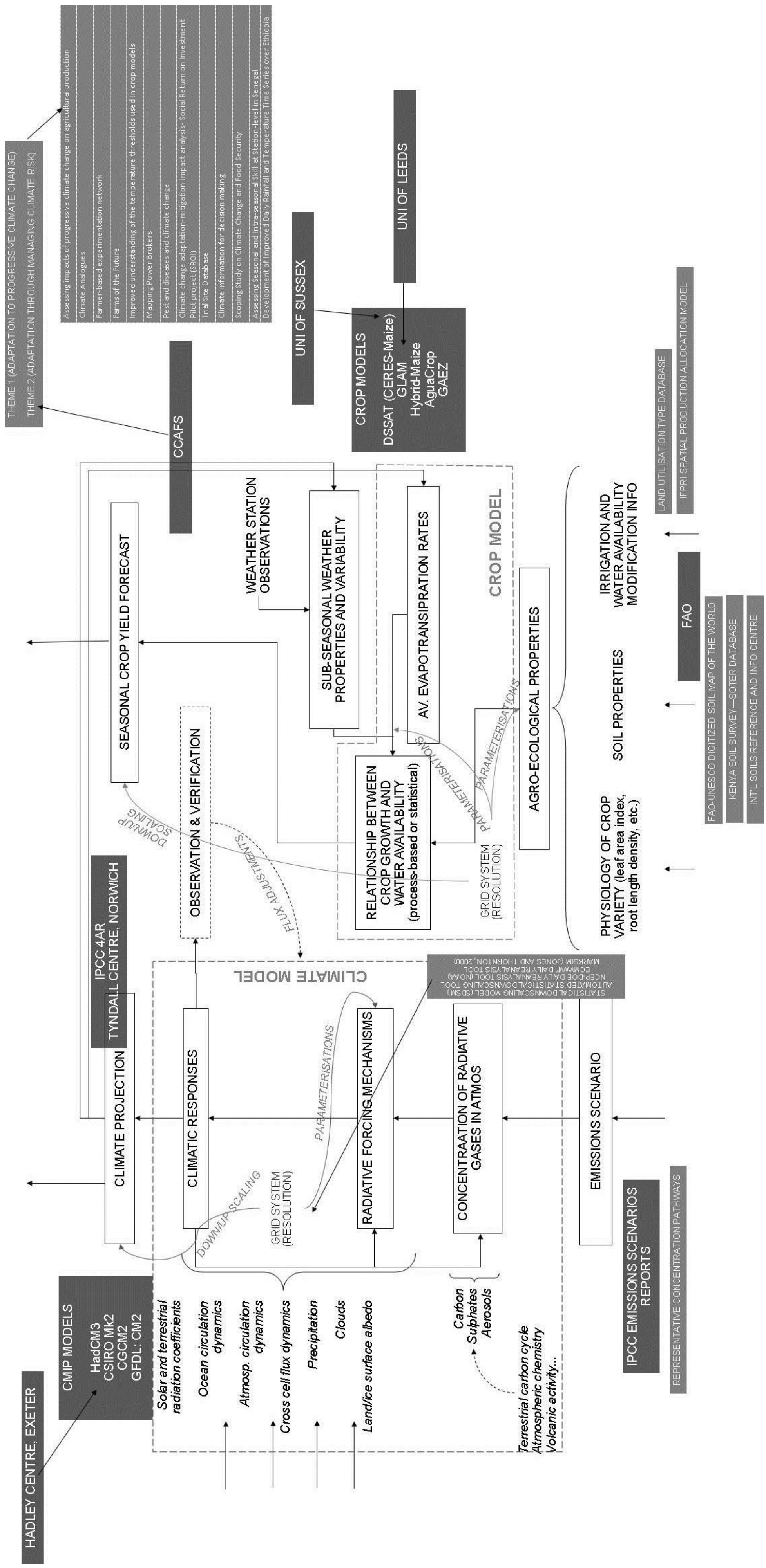

Figure 5 Initial production chain diagram for climate-crop model projections, showing the main process stages (white box); input data (italicised text) and key actors, models, and sources of information (grey boxes) that represented potential points of entry for the research. The diagram was produced through a review of peer-reviewed and grey literature

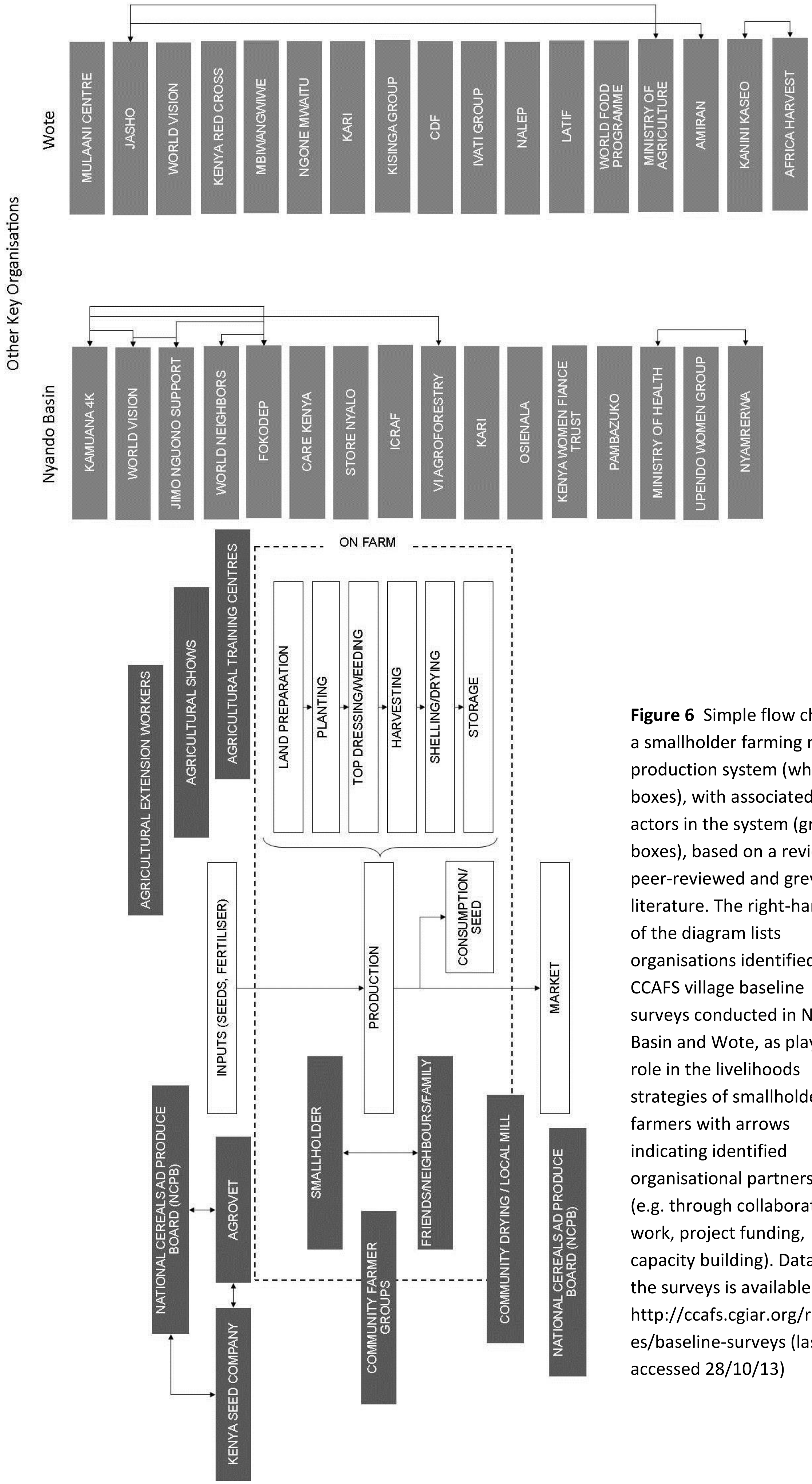

Figure 6 Simple flow chart of a smallholder farming maize production system (white boxes), with associated key actors in the system (grey boxes), based on a review of peer-reviewed and grey literature. The right-hand side of the diagram lists organisations identified in the CCAFS village baseline surveys conducted in Nyando Basin and Wote, as playing a role in the livelihoods strategies of smallholder farmers with arrows indicating identified organisational partnerships (e.g. through collaborative work, project funding, capacity building). Data from the surveys is available at http://ccafs.cgiar.org/resources/baseline-surveys (last accessed 28/10/13)

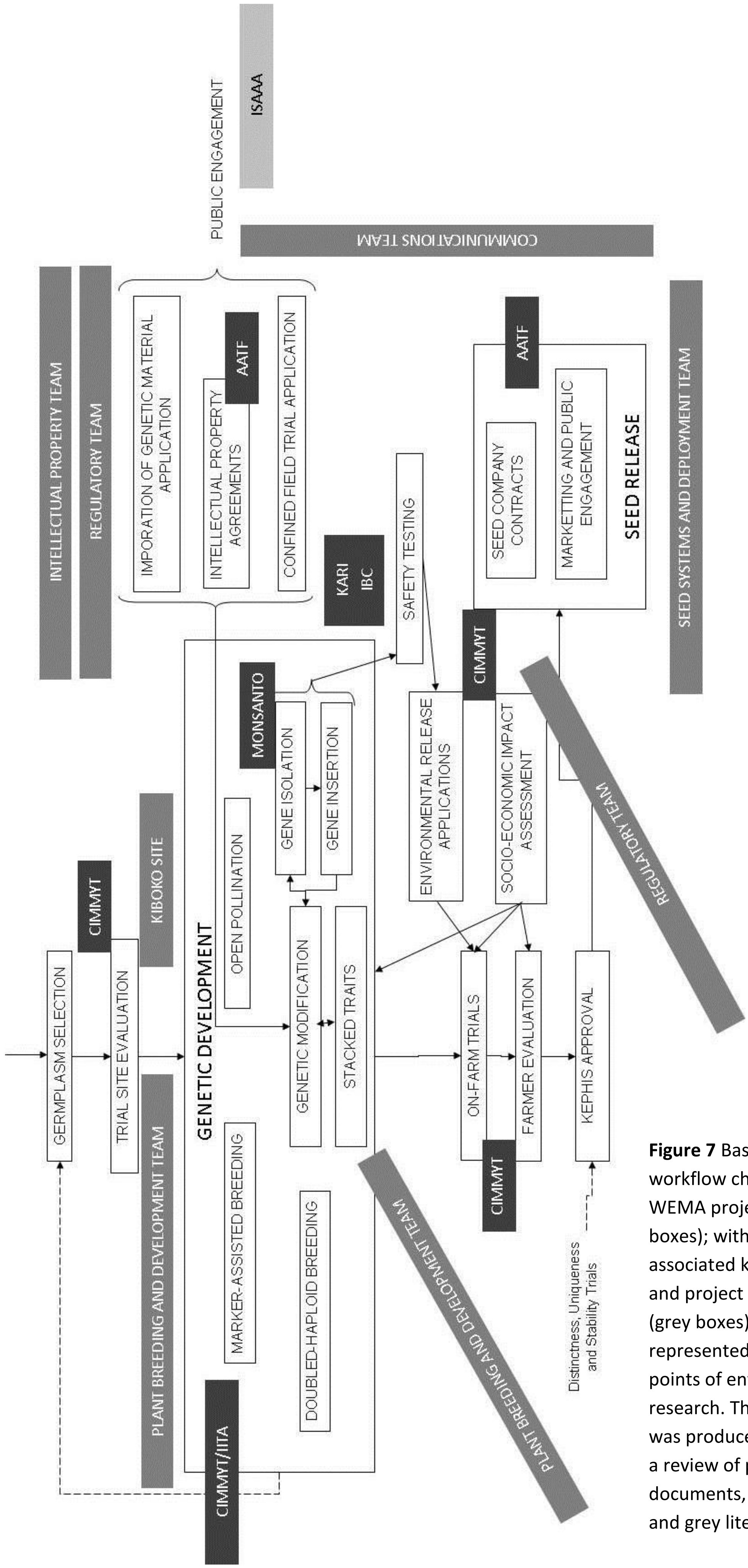

Figure 7 Basic project workflow chain for the WEMA projects (white boxes); with associated key actors and project teams (grey boxes) that represented potential points of entry for the research. The diagram was produced through a review of project documents, web-sites and grey literature

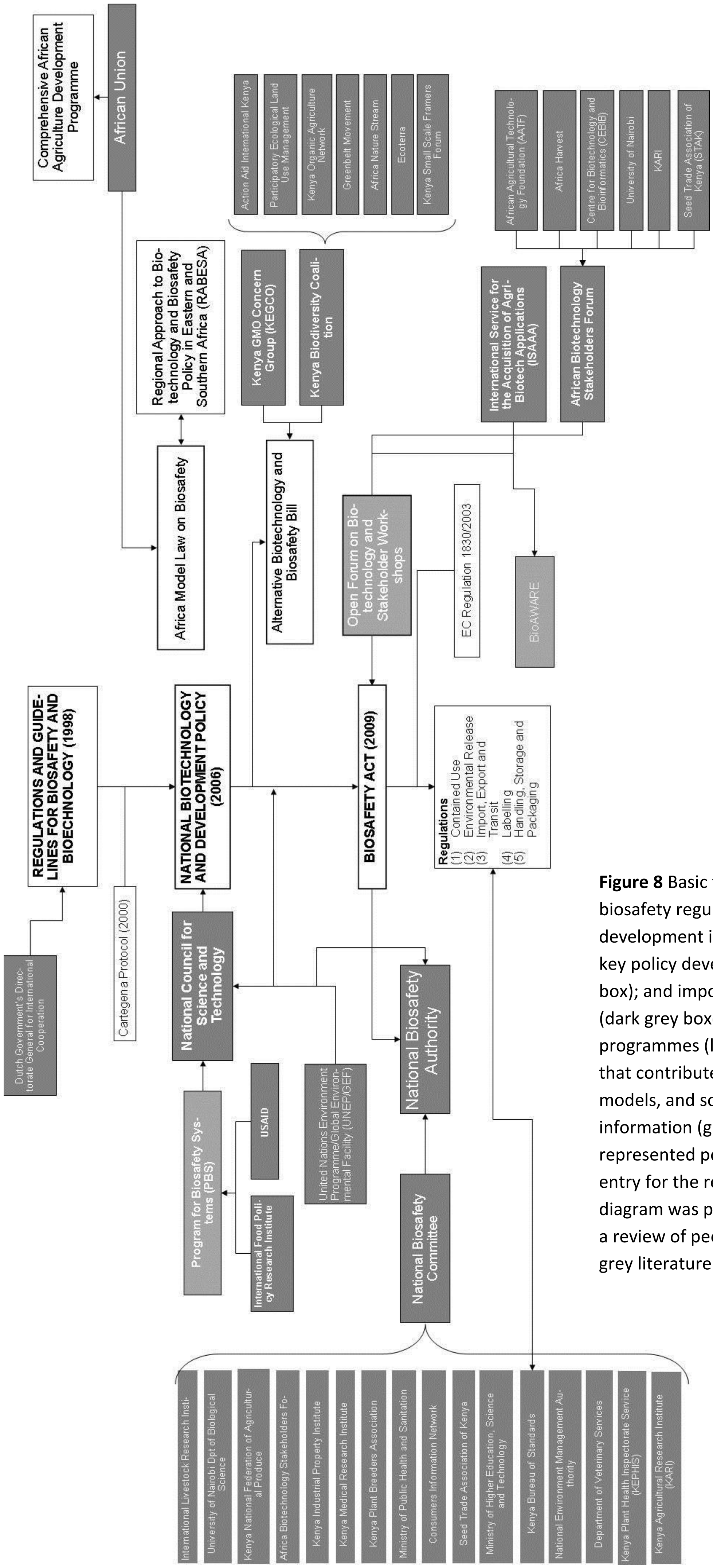

Figure 8 Basic flow chart of biosafety regulation development in Kenya, showing key policy developments (white box); and important actors (dark grey boxes) and programmes (light grey boxes) that contribute at each stage, models, and sources of information (grey boxes) that represented potential points of entry for the research. The diagram was produced through a review of peer-reviewed and grey literature

Research Sites

The first site of the research was the UK Meteorological Offices in Exeter, where I gave a research outline seminar and discussion, and organised a number of meetings with climate scientists and communications staff involved in the Climate Science Research Partnership (CSRP). This was an opportunity to conduct interviews, but also to observe the working environment and professional relationships within an internationally influential climate modelling centre. Subsequent attendance at CSRP events and discussions with people from the Meteorological Office, as well as contact with CGIAR crop modellers and representatives of the Meteorological Department in Kenya, provided a means of getting an ethnographic insight into climate-crop modelling as an institutional process.

In Kenya, a ten-month period of research was conducted through an affiliation with the CCAFS cross-institute research programme of the CGIAR, and as a consequence of this affiliation, I was based at the World Agroforestry Centre (ICRAF) and International Livestock Research Institute (ILRI) campuses in Nairobi. These CGIAR campuses host a number of agricultural research institutions, including CIMMYT, ICRISAT, ISAAA and the AATF, as well as bioscience research facilities. Being based within the CGIAR centres, and contributing to CCAFS projects, as well as work on the CIMMYT Maize Growers Survey, gave direct access to and experience of the working of the CGIAR system and that of some of the partner institutions of the DTMA and WEMA projects. Informal discussions, conferences, and observations of institutional meetings became a part of the institutional ethnographic research itself. Personal and professional connections made through this affiliation also led to opportunities to visit CIMMYT maize breeding stations, including the Kiboko site in Makueni district where confined trials of WEMA varieties are on-going, and locations of CIMMYT work outside of Nairobi.

The Nairobi base, and the CGIAR affiliation, provided opportunities for conducting more formal interviews at the headquarters of the Kenya Agricultural Research Institute, the AATF and Monsanto, as well as the offices of the National Biosafety Authority (NBA) and the Ministry of Agriculture. Whilst in Nairobi, opportunities were also taken to participate in the monthly Open Forum on Agricultural Biotechnology meetings, the Humanitarian Future's Programme's Climate Knowledge Exchange workshop, and the NBA's National Biosafety Conference (there is more information about these events below).

Two districts of contrasting agro-ecological conditions, but a similar predominating land use of smallholder rain-fed maize agriculture - Nandi/Nyando (two adjoining districts considered together in this research) and the Makueni district, found in Kenya's 'moist-transitional' west and 'dry mid-altitude' mid-south respectively – were chosen as the sites for engaging with smallholder maize farmers. Figure 9 highlights those areas of Kenya, and their agro-ecological designation, for which maize farming accounts for at least 5 per cent of land use and identifies the regions of study. Within these regions, data collection took place in and around sites of CCAFS on-going monitoring and baseline survey data collection (Katuk-Odeyo (Lower Nyando); Wote-Kithoni (Makueni)), both to take advantage of opportunities for data collection as part of the CCAFS survey team, and to build on the rich data sets that already exist as a product of these surveys. An opportunity was also taken to work with an agricultural training centre in Nandi District (Kipkaren-Nyenyilel) in order to facilitate additional data collection. More information on the agro-ecologies and recent histories of the research sites is presented in Chapter Six.

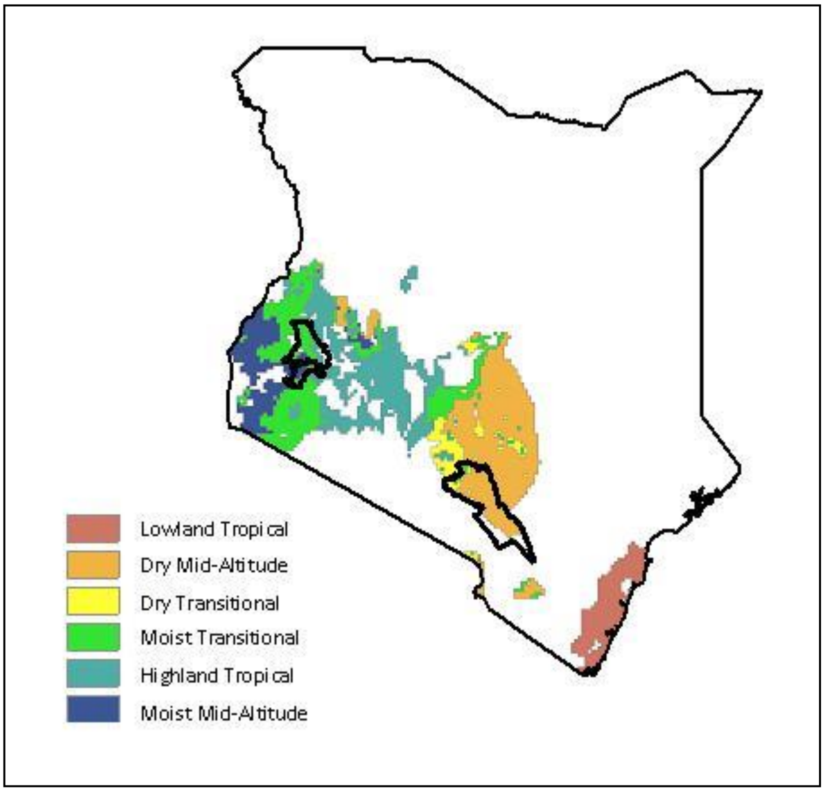

Figure 9 Map showing agro-ecological conditions in areas in which maize agriculture accounts for at least five per cent of land use. Data provided by CIMMYT (June 2012), shapefiles of Kenyan districts from arcgis.com, and map created using ArcGIS™ software

In addition to these main research sites, visits were made to agricultural shows in Machakos and Eldoret, in which farmers have opportunities to learn about new products, technologies and techniques at stands run by private companies, research centres, and agricultural extension workers. Visits were also made to the National Cereals and Produce Board, the Kenya Seed Company's 'Seed Plaza' and Research Station, and Kenya Health and Plant Inspectorate Service (KEPHIS) offices in Kitale, Western Kenya. Each empirical chapter include descriptive prose that gives an insight into some of the research locations and contexts and some self-reflection on my own construction of knowledge in the process of conducting research in these locations.

Details of Data Collection[52]

Data collected on climate-crop modelling consisted of a total of eighteen semi-structured interviews with modellers at the Meteorological Office in Exeter, the CGIAR CCAFS group, and the Kenya Meteorological Department (KMD) in Nairobi. Interviews were audio recorded and then transcribed and annotated with notes taken during the interview. Detailed field observation notes were taken from visits to the Meteorological Office, participation in the Humanitarian Futures Programme's Climate Exchange Workshop (held in Nairobi in March 2012), which involved participants from the KMD, the World Meteorological Organization (WMO) and the IGAD International Climate Prediction and Applications Centre (ICPAC), and CCAFS seminars. Secondary data compiled as part of the 2010 meta-analysis survey of crop modellers conducted by the CCAFS group of the CGIAR was also analysed.

In both smallholder farming regions observations of, and participation in, on-farm activities were combined with semi-structured interviews and group scenario workshops (described below) were conducted. In both cases a significant proportion of data collection was opportunistic and, although basic household information was recorded alongside transcripts and field notes, participants ranged from heads of household to whole families or several gathered neighbours and, as such, systematic sampling was not possible. Interviews were also conducted with 'key informant', farmers with holdings ranging between 1 and 10 acres in size that were identified with the help of agricultural extension workers and village elders. From these key informants there was some degree of snowball sampling, as they introduced neighbouring farmers and friends. The interviews sampled a combination of males and females (targeting the person or persons in the household responsible for farming) and, as much as possible, a relatively even

[52] The specific data collected is detailed with the Methodology Appendix

representation of age groups (respondents ranged from approximately 18 to 60 years old). Interview transcripts and notes taken during workshops and farm visits were manually coded and basic summary statistics were used for analysing the outputs of the workshop exercises and the secondary survey data. The aim was to generate data sets from the two districts that were comparable, although not for the purposes of comparison, however logistics and other limitations prevented them from being perfectly identical. In the Makueni district, data was collected as part of the CCAFS survey team (which included agricultural extension workers from the Ministry of Agriculture). This provided an excellent opportunity for the observation of farming practices and some professionally facilitated workshops, although the data collection was not specifically designed around the research, and scenarios were only considered as part of a three day workshop exercise for which I was one of a group of facilitators, so supplementary interviews with farmers were necessary. In the Nyando/Nandi region, CCAFS survey data had already been collected in the Lower Nyando basin offering a good comparable dataset. In this district I was the primary facilitator of the workshops and they were more focused on participatory scenario development, although because of logistics, a proportion of the data collection was focused outside of the CCAFS survey site (in the Nandi villages of Kipkaren and Nyenyilel) where facilitation support could be gained through working with a local agricultural training centre.

A total of twenty-one semi-structured interviews were conducted with representatives of the DTMA and WEMA projects including crop breeders from CIMMYT and KARI, breeding station managers, CIMMYT social scientists, project management and seed systems coordinators from AATF, regulatory team members, and a communications manager from Monsanto. Primary data was also collected in the form of observatory notes taken during three visits to maize breeding stations, tours of KARI facilities and Monsanto offices, and observations of WEMA partners at agricultural shows and participation in meetings with CIMMYT and CGIAR staff at the World Agroforestry Centre. Coding and analysis was also done on project reports and documents including WEMA biosafety applications, which were accessed with special permission from the NBA.

Policy processes and narratives around the writing and formalisation of the 2009 Biosafety Act were studied through a qualitative analysis of policy documents and peer-reviewed literature combined with retrospective interviews with some of the actors and institutions that played a key role in the construction and realisation of the Biosafety Act (from the NBA, ISAAA and KARI). Data sources for this element of research were identified through a snowball sampling method that began with discussions with key informants from ILRI, ABSF and ISAAA. Debate over the 2012 labelling regulation was directly observed through participation in biotechnology stakeholder forums and the 2012 Annual Biosafety Conference held in Nairobi, and discussed in semi-structured interviews with representatives from the National Biosafety Authority, Kenya Organic Agriculture Network, ABSF, Kenya Bureau of Standards, the Cereal Miller's Association, the International Service for the Acquisition of Agri-Biotech Applications, and WEMA organisations (KARI, Monsanto, and AATF). The significant moment that took place in November 2012, when the Ministry of Public Health imposed a national ban on the importation and consumption of GM foods in Kenya, was experienced and analysed through media reports and discussed in semi-structured interviews with representatives of the NBA, AATF, ISAAA and ABSF.

The Methodology Appendix provides a detailed list of interviews and primary and secondary data sources and assigns codes that will be used throughout the empirical chapters to refer to information that came from these sources. It also contains details about the coding strategy used in analysing the various documents and data sources gathered.

Participatory Scenarios and Stakeholder Workshops

The research involved facilitating and participating in a number of fora for knowledge exchange and these provided particularly useful opportunities for observing the ways in which narratives become shaped through interactions:

- The Humanitarian Futures Climate Knowledge Exchange workshop was an opportunity for exchange between climate modellers and representatives of humanitarian and civil society groups.
- Monthly Open Forum on Agricultural Biotechnology meetings, held in Nairobi, were an opportunity for communication and discussion around research and policy developments associated with agricultural biotechnology between research centres, scientists, policy makers, private sector organisations, and civil society and farmer groups.
- The Annual Biosafety Conference, held in November, was also an opportunity for debate, particular between the NBA and representatives of pro- and anti-GM groups about the nature and status of biosafety policy development in Kenya.

I observed and participated in these various fora, made connections, and conducted informal discussions with other participants. In the case of working with smallholder farmers, however, I purposefully created opportunities for knowledge exchange, whereby participants were involved in collectively conceiving future scenarios of change. The concept and design of which are described in more detail here.

The participatory scenario workshops were a variant of methods used by Anthony Patt (Patt et al., 2005) in Southern Africa, Kasper Kok and colleagues (Kok et al., 2007), and the USAID funded Climate Change Collective Learning and Observatory Network in Ghana (Tschakert and Dietrich, 2010), and they involved both a reflection on a history of agricultural challenges and opportunities and a discussion of preferences for different pathways of future change. In the methodological framework for anticipatory learning presented by Tschakert and Dietrich (2010) they explain the importance of incorporating 'lessons learnt from the past' with 'monitoring and analysis of trends to anticipate future events':

> 'Memory, also referred to as 'experiential grounding', serves as the knowledge base underlying the capacity for anticipating and envisioning future uncertainty and surprise... identifying and monitoring slowly changing variables such as rainfall patterns and reflecting on and integrating new knowledge allows for a better understanding of processes that are already underway' (Tschakert and Dietrich, 2010: 12)

A participatory scenario methodology has applicability across a number of the risk governance models described in table 2 (previous chapter). It has been increasingly adopted in different guises within a number of environmental policy and impact studies (Enfors et al., 2008, Kok et al., 2007, Patel et al., 2007) and offers an opportunity for participant-led identification of structures and mechanisms of vulnerability and adaptation, whilst simultaneously offering a platform for information sharing, deliberation, and subsequently the building of adaptive capacity. Kok et al. (2007) describe scenarios as 'an excellent vehicle for bridging knowledge systems, enhancing dialogue, and educating stakeholders' (p.13). Participatory scenarios are usually developed through workshops in which a cross-section of the community participate in sharing and deliberating on visions for the future and can, for example, act as a methodology for risk assessment and management, which may or may not draw on information, such as climate model projections and science and technology developments, as contributors to the discussion (Huber-Sannwald et al., 2006, Voinov and Bousquet, 2010, Whitfield and Reed, 2011). Such an approach has the potential to provide an assessment of future scenarios that is based on the ways in which local stakeholders might utilise, experience and adapt, not just to the ecosystem but to the changing social, economic and political structures of which they are part. Patt et al. (2005) have demonstrated that, by combining climate forecasts with local experiences of historic and changing climates and using semi-quantitative description (such as the probabilities of 'above-', 'about-' and 'below-' normal rainfall), within participatory workshops, it is possible to communicate detailed climate projections and their uncertainties to smallholder farmers (in their case subsistence farmers in Zimbabwe) and even engage in discussion about complex concepts, such as El Niño. A few examples (e.g. Robinson et al., 2008) have shown that the environmental values of stakeholders can be changed as a result of learning through participatory workshops, however, there is much more to be learnt about the ways in which different knowledge systems are prioritised within these participatory forums.

In both districts of research CCAFS household baseline survey data were analysed to develop a picture of what the key agricultural changes in each district were over the past 10 years and what has driven these changes, particularly in maize farming[53]. Informed by this data, the workshops began with a collective discussion of recent challenges, opportunities and trends in the climate, economy, society and politics that are affecting farming and describe and evaluate ways in which they have attempted to address challenges and opportunities. Participants were also briefed on and asked to discuss projections on climatic change, and uncertainty within projections, as well as research developments and policy debates around genetic modification in Kenya. The purpose of presenting this information and addressing these questions was to draw out a collective experience of, and expectation about, future change as well as identify major factors or constraints on adaptation, with a focus on the adoption of genetically modified crops as one (sub) pathway of change.

Discussion then focused on the relative merits and challenges of three main pathways (and one sub pathway) of future agricultural change, as well as a status quo scenario (no change pathway). The pathways considered were:

- Changing land management, preparation and inputs
- Adopting alternative maize varieties
    - Adopting GM maize
- Alternatives to maize for market and home consumption
- No change scenario

Participants were encouraged to discuss and describe the meaning of these pathways by identifying pathway ‘components’ – tangible and practical changes that each pathway might involve, in order to promote ownership and better facilitate the imagining of the pathways. In describing merits and challenges, participants were encouraged to think about both ‘push’ and ‘pull’ factors that might instigate the changes, identify the ‘actors’ (inclusive of individuals,

[53] This data was extracted from a large dataset using a frequency matrix analysis (a full description of the data analysis can be found in the Methodology Appendix).

officials, organisations, and non-human actors) responsible for these factors, and estimate the likelihood and timescales over which such factors might materialise. Information was recorded in a participatory and interactive manner, using large charts and post-it notes, and revisited (and triangulated) through a deliberative comparative analysis of the alternative pathways.

Workshops were organised and facilitated with the help of local councillors and agricultural extension workers and ranged in size from 6 to 30 participants. As they were mostly conducted in public places, the workshop profiles were affected by passer-by participation. All groups contained a combination of male and female participants and each had at least two participants from both the 18-25 and 40+ age groups.

Iteration and Cycles of Learning

The research process was not a linear one. In accordance with the principle of reflexivity in addressing my own ambiguities and ignorance as a researcher, I completed a research diary and continually wrote, read and iterated my approach. As I conducted interviews or made observations, I was constantly being exposed to new aspects of the scientific culture; new components of the knowledge production chain; new social, professional and historical connections within and beyond the expert communities; and new literatures and outputs. As such, there was a perpetual cycle to the research, which is reflected in an adopted snowball approach to sampling and a number of feedback and follow up interviews and communications with participants.

Box 2: Research Diary Excerpt: An Example of a Cycle of Learning

I had read in the initial background information about the WEMA project, in which it was claimed that ''the maize varieties developed under WEMA are expected to increase yields by 25 per cent under moderate drought'. Initially, interviews with WEMA representatives had suggested that this was an evidence-based claim and yet no-one knew the origins of the figure. I decided to go back to project documents and attempted to trace the citation and recitation of this figure across a relatively long paper trail of (initially) project documents and (later) peer-reviewed literature. I eventually determined that it was based on experimental research conducted by Monsanto in in the American Midwest. Confusingly, however, although the data presented in these studies showed that experimental transgenic yields were higher, they did not indicate the 25 per cent growth suggested in the official WEMA outputs. I then talked through my findings with another WEMA representative, who explained that I had misinterpreted the initial figure, which was actually given as a target figure as opposed to a projected performance for the technology. He explained that it is in part a political figure, based on the need to justify investment, but that the ultimate success of the project will not actually depend on yield figures, but on farmer adoption of the technology (based on their own evaluations of it). This dynamic of different systems of technology evaluation and the pressures on WEMA to produce an impressive evidence-based expectation of outcomes went on to become an important theme of the research, and something that I discussed at length with other participants, as a consequence of this finding.

Conclusion

The approach taken in this research to identifying narratives and capturing, analysing and interpreting the process by which they are contested and negotiated necessarily engages with the subtle and hidden internalisations and interpretations of narratives and their flows and disconnections across spaces and groups. It is multi-sited and adopts an ethnographic approach in order to appropriately engage with a breadth of actors involved in the shaping of the future of Kenyan maize agriculture and the nuances and personal nature of their involvement and their narratives. Combining observations with more structured data collection methods and the creation of fora for knowledge exchanges allows for the creation of a large set of data that can be contextualised within observations of, and a reflection on experiences of being part of, the research field.

An interpretation of the data collected is presented in this thesis and, whist it has an evidence-base, which is the product of the approach detailed in this data collection methods chapter (and in the associated appendices) and a conceptual framework (described earlier), it is, of course, also based on the assumptions and values of the author. This chapter has provided a description of the origins and basis of the thesis narrative, and, as is argued across the thesis, being transparent about the underlying knowledge of narratives and its incompleteness is also essential basis for their contestation and renegotiation.

The following chapters present this narrative, not as an authoritative or complete statement about the reality of Kenyan agricultural adaptation, but in contribution to its continued negotiation.

Chapter Five: Climate-Crop Modelling

Complexity Logic and the Negotiation of Evidence

In this, the first of four empirical chapters, the context, nature and communication of projections of future change in climates and crop productivity are described. Using a constructivist approach, and drawing particularly on Stirling's (1999) schema of incomplete knowledge, the chapter focuses on key processes in climate-crop modelling. Insights are drawn from interviews with climate and crop modellers, and triangulated with data from a meta-analysis survey of crop modelling conducted as part of the CGIAR's CCAFS programme in 2010, and peer-reviewed crop and climate modelling literature, in order to understand the constructed and changing nature of this knowledge generating process. This chapter particularly concentrates on the tension between a 'complexity logic' in the construction of Kenya's agro-climatic future – one which equates increasing complexity in modelling with increasing proximity to reality and by extension (through an evidence-based policy logic) to better informed policy – and warnings, that increasingly come from within the modelling community itself, against both objectivist interpretations of model predictions and the privileging of science as the sole constructor of this future. It is argued that persistent uncertainty, ignorance and ambiguity belie a conventional wisdom within the modelling community that links increasing data, observation and complexity to a more objective and accurate science. However, it points out that there is growing recognition that the expansion of methodological options and alternative interpretations of system dynamics that have resulted from the global growth of the modelling endeavour is increasing the space and need for more participatory and deliberative approaches to modelling, particularly in response to incomplete knowledge within the production and interpretation of evidence. The central question of the research is addressed here by revealing the social and institutional contexts in which these ideas and approaches are shaped and focuses predominantly on the incomplete nature of knowledge that is produced within these contexts.

The Context of Climate-Crop Projections

The impressive glass-walled edifice and almost extra-terrestrial roof structure of the Hadley Centre, at the UK Meteorological Offices in Exeter, immediately impresses on visitors its standing as an institute of the state of the art. Within its chasm-like interior, the Centre bustles with activity; countless flat-screens display a dizzying animated collage of real-time and forecast images of weather systems and there is a constant flow of smartly dressed professionals moving along the glass-sided stairwells and suspended walkways, swiping their security cards to access open plan offices and conference rooms. I was grateful to be following one such suited (and senior) scientist as he guided me through some of the climate modelling operations of the Centre and introduced me to some of the contributing people and research programmes, because I found myself in a permanent state of disorientation. Like the building, the scale and the technicality of the climate modelling endeavours of the Centre are overwhelming. From the development of statistical models to evaluate the correlation between forecasts and observations of sea surface temperature (SST)-East African rainfall teleconnections to the refinement of global environmental models of centennial scale biogeochemical feedbacks, there was a lot to try to get my head around and infinitely more gaps to attempt to fill in.

Nevertheless, through observing the humanity of canteen discussions, coffee breaks and office interactions, it became clear that the Centre is much more than just an industrial factory of climate forecasts. The Centre has a real sense of collegiality and a culture of intellectual sharing, in which colleagues mutually encourage and celebrate innovation and interdisciplinary team work. Climate modellers spoke passionately about the work being conducted by the members of the Climate Science Research Partnership (CSRP) and the Humanitarian Futures Programme (HFP) in evaluating the usability and usefulness of climate outputs in Africa and described the iterative and collaborative process of creating products driven by the demands and needs of smallholder farmers. Within this environment that initially appears to embody the futuristic (artificial) simulations of its intellectual endeavour, these programmes represent an essential and valued connection to the real world.

The context of climate modelling is one of global scientific endeavour, characterised by disparate and dispersed experimentation, information from which is communicated through the conventional outputs of scientific journals and gradually feeds in to centralised modelling programmes such as that which takes place at the Hadley Centre. The scale and complexity of this global science is reflected in the assessment reports of the Intergovernmental Panel on Climate Change (IPCC), which represent the most complete and high profile attempts at collectivising contemporary research on climatic change. The reports are dominated by references to models and model ensembles, such as those compiled by the Coupled Model Intercomparison Project (CMIP). The recent IPCC fifth assessment report (AR5) on the physical science basis of climate change makes reference to over 9000 studies[54].

[54] Report available at http://www.ipcc.ch/report/ar5/wg1/ (accessed 5/11/13)

The IPCC AR4 relies particularly heavily on the use of coupled atmosphere-ocean general circulation models (AOGCMs) (of which it refers to 23), for simulating global scale processes over multi-decadal periods. These are computer driven models that run thousands of simultaneous equations describing processes derived from fundamental laws of thermodynamics and fluid motion (Le Treut et al., 2007). The outputs of these models are generally used to develop projections of atmospheric temperature and precipitation. Less-complex modelling alternatives to AOGCMs often deal with isolated elements of atmospheric processes at regional scales or at single points in ways that are more sophisticated than GCMs (e.g. one dimensional radiative-connective models often have more detailed radiation variables), however, the IPCC's own preference for general circulation models is summed up in their own description of a 'model hierarchy' (Randall et al., 2007), which ranks model-types by their proximity to realism. This is a concept that is based on an understanding of real-world climates as highly complex systems and therefore that the resolution and complexity at which the interaction of surface processes, radiation and dynamics are modelled is a measure of the realism of model outputs (Shine and Henderson-Sellers, 1983):

> 'Many scientists believe that the ultimate goal of climate modeling should be fully comprehensive, three dimensional models of all elements of the climate system including very high resolution and as much detail as possible' (Schneider, 1992: 17)
>
> 'The apex [of the modelling pyramid] suggests that when all facets are correctly and adequately incorporated at a high enough resolution a model, presumably identical to the real climate, results' (Shine and Henderson-Seller, 1983, cited in Shackley and Wynne, 1997 - brackets added by Shackley and Wynne.)

Such a view was expressed by a climate modeller at a CCAFS seminar that I followed online. He was obviously frustrated by the limitations in modelling capacity and quick to link uncertainty to a lack of model complexity, and ultimately a lack of ambition on the part of funding bodies:

> 'Computer power is being delivered in greater amounts but we are becoming aware of the extent to which this is such a big problem that it is beyond the community as it currently stands. So one view is that we might stop messing around trying to find things like the Higgs-Boson and put some serious money into climate science, as it is an established real problem that is in front of us, and be able to undo some of those uncertainties that we have spoken about and difficulties in the models that are so long standing. Differently, we wish that we could leverage the kind of funding that goes in to some parts of physics for this kind of work, and we should be able to given the immediacy and the reality of the problem' (Sem1)

In the IPCC's 'Historical Overview of Climate Change Science' presented at the very beginning of the Working Group 1 contribution to AR4 it is argued, for example, that 'incorporating the full complexity of interacting processes and feedbacks... might ideally be required to fully verify or falsify climate change hypotheses' (Le Treut et al., 2007: 98). The suggestion here is that complexity represents a means of legitimacy, such that complex models are granted authority to verify (make a judgement about the truth of) hypotheses derived through less complex means.

Since the IPCC's first assessment report in 1990, global climate models have developed to incorporate cumulatively the effects of (in chronological order): radiative forcing and long term GHGs; atmospheric chemicals and aerosols; terrestrial carbon cycling; tropospheric ozone; cryospheric albedo; coupled ocean atmosphere dynamics (e.g. ENSO); cloud cover, thickness and height; and much more (Le Treut et al., 2007). Increased complexity and resolution has been achieved through advances in computational capacity, which allow for the running of increasingly discrete equations (i.e. sub-divided parameters), and improved understanding and observation of physical processes. The growth of the global climate model intercomparison project (CMIP), a key source of data utilised in the IPCC assessment reports, since its beginnings in 1995, is also indicative of the growth of the global project of climate modelling. The initial CMIP1 and CMIP2 experiments run in the mid-1990s involved the participation of 25 models, representing almost the entirety of the worldwide developed coupled climate models at the time. These two experimental collections present day control runs (CMIP1) and 1% per year CO_2 increase experiment data (CMIP2). By comparison, the current CMIP5 experiment, the data from which will be utilised in the IPCC's fifth assessment report, has been participated in by more than 50 models (including high resolution atmosphere models and earth system models as well as AOGCMs) from 20 modelling groups, and involved the running of AOGCMs in over 30 different configurations (characterised by different Representative Concentration Pathways; specified CO_2 concentration increases; aerosol projections; volcanic simulations etc.) in both long-term and near-term experiments.

In spite of this growth in complexity and model intercomparisons, however, knowledge about future changes remains incomplete. A number of respondents pointed out that, in spite of the growing sophistication of models, their projections remain diverse and divergent (CS2; CS19; CS21), this can be seen for example, by comparing the uncertainty ranges evident in the average global temperature increase projections across the IPCC assessment reports, from 1992 to 2007, across which a broad margin has remain relatively constant (IPCC, 2007, IPCC, 2001).

In recognition of their limitations and, counter to the convention of focusing on the simulation of reality, projects such as the HFP and the work of groups such as the Hadley Centre's CSRP are advocating for the application of climate modelling to generating information relevant to particular policy problems, and engaging critically with how knowledge generated through these modelling endeavours is communicated and used. The imperatives of research funding, and the growing number and influence of projects such as the CSRP, increasingly require members of the scientific community to engage with the usability and implications of the information that they produce. However, particularly when it comes to thinking about knowledge gaps and the weaknesses of model projections, modellers can find themselves in the difficult position of both justifying an investment in modelling and acknowledging its flaws:

> 'The recent disagreements in the literature (like differences between David Lobell and Chris Funk) about the directions and even model reliability for East Africa suggest to me that we need to implement adaptation strategies for moderately severe cases even if we don't know the exact changes to plan for. The models aren't very good at predicting trends yet. Because of this shortfall, we should be focusing on getting better observations (field size, maize varieties in use, nexrad rainfall estimates). The observations would do two things: provide better data to farmers, and provide better data for model calibration.' (CS19)

This statement offered by a key climate science informant highlights some of the challenges of using climate impact projections in the light of incomplete knowledge. It is evident in the way that the informant struggles between realisations of the weaknesses of models predictions – 'the models aren't very good at predicting trends yet' – and the logic that such evidence should provide the basis of best policy. This kind of contradiction is not uncommon amongst climate and crop modellers, who often simultaneously believe in the value of their endeavours and have institutional and economic incentives to demonstrate the policy utility of their outputs, and yet are aware too of the limitations of these outputs.

As is argued in the following sections of this chapter, the response to this tension often depends on a particular framing of incomplete knowledge within modelling, in which it is reduced to a probability distribution. Model ensembles, which may represent a combination of different models or one model run several times with a range of different parameterizations, are regularly presented (including within the IPCC reports) as being representative of 'risk'. In other words the range of model projections are interpreted as representing a range of possible future outcomes and the level of model agreement (or disagreement) interpreted as representing their probability. Moreover, where projections are completely divergent, moderate change often becomes akin to most likely change as though a single peaking probability distribution fills the gap between two extremes. This is an example of closing down of incomplete knowledge to risk; a denial that there may be uncertainties, ambiguities, and ignorance that are common across models and that possibilities might exist outside of model projections, which is somewhat of a cultural convention within the scientific community (CS2, CS10. CS20).

The logic of ‘getting better observations… [to] provide better data for model calibration’ (C19) such that risk is reduced and, over time, adaptation strategies can be better designed around a shrinking probability distribution curve, fits within a particularly understanding of incomplete knowledge as well as a linear evidence-based understanding of policy. Targeting the production of best evidence is of course a noble endeavour. Reducing ignorance (particularly through improvements in observed data) about the agro-climate system undoubtedly goes someway to improving the utility of model projections, but a focus on the probabilistic presentation of model outputs, inevitably masks uncertainties within them. Later sections discuss the policy utility of models in light of their incomplete nature, including their use as participatory and non-predictive learning tools. In the following section the nature of incomplete knowledge in climate crop modelling is explored in more detail with the aim of exposing more explicitly its uncertainties, ambiguities and ignorance.

Producing Climate-Crop Projections

Figure 10 is a distillation of the elements of similar diagrams presented by Tatsumi et al. (2011), Thornton et al. (2009), and Nelson et al (2009). It provides a schematic representation of the stages involved in producing a crop projection, and represents a later iteration of the diagram shown in figure 5. The steps in the chain are points of reference for positioning the particular data and decisions discussed in this chapter within the overall endeavour of climate-crop modelling.

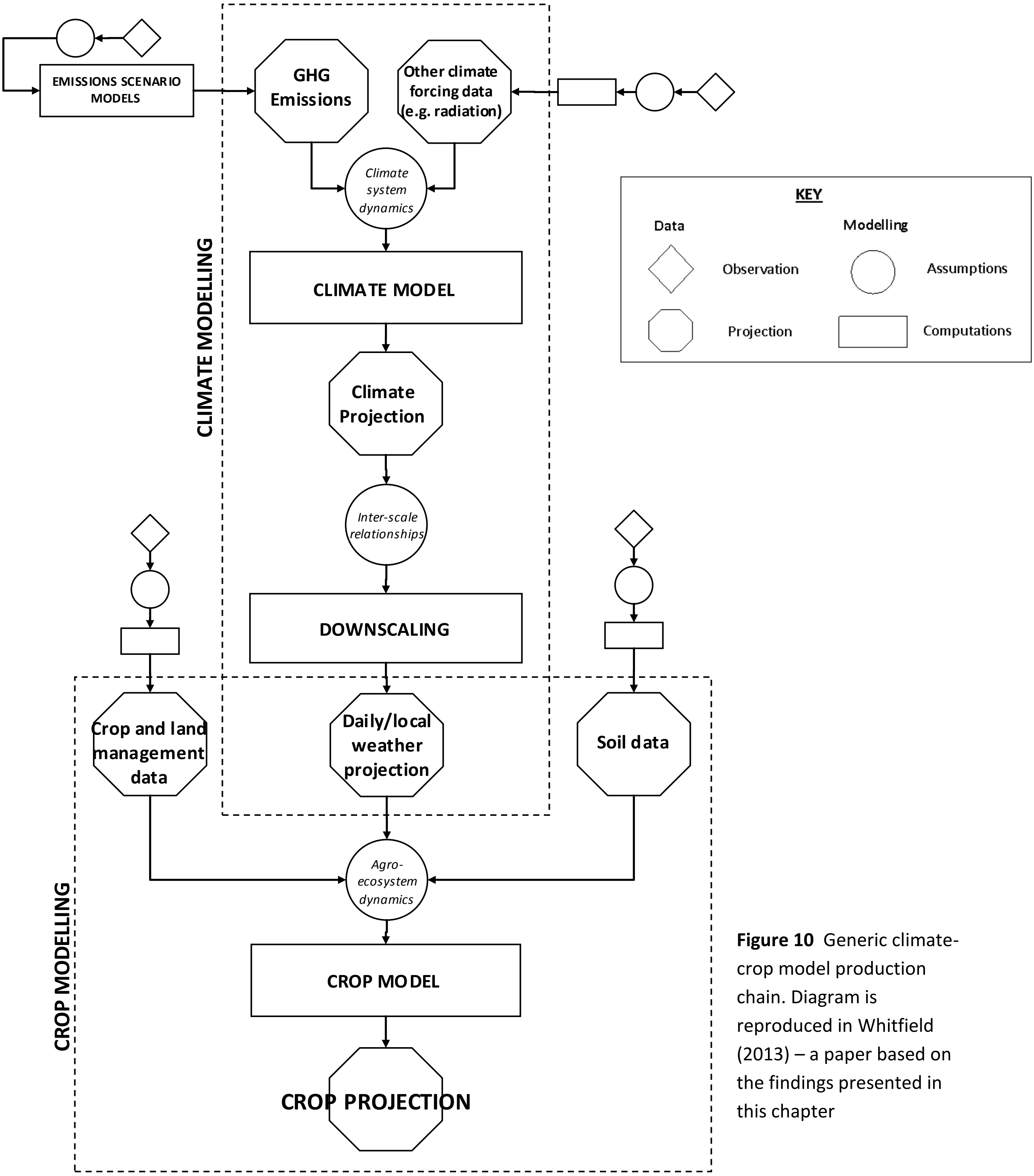

Figure 10 Generic climate-crop model production chain. Diagram is reproduced in Whitfield (2013) – a paper based on the findings presented in this chapter

In crop modelling, information that describes limits on photosynthetic potential and water availability (daily rainfall and maximum and minimum daily temperatures), soil moisture capacities and mineral properties, plant phenological development requirements (i.e. the response of the plant to water availability, radiation, and daily temperatures), and agricultural practices are all essential inputs to the models calculation of yield. Each of these sets of data has a production chain of its own, which continues to branch (as hinted at within the diagram) well beyond the scope of this research. The integrity of the final crop projection will depend in part on the accuracy of the input projection data.

In the production chain of the required input data for running a crop model (downscaled rainfall and temperature data, soil data, and crop and land management data) a repetitive pattern of observation-assumption-computation-projection can be identified. The computation of future greenhouse gas emissions, a key input parameter for the running of crop models, for example, is achieved through the processing of data on observed emissions (or emissions drivers) based on assumptions about future behaviour. Similarly global scale climate projections, which play the role of primary (or observation) data in the subsequent stage of the process, undergoes a computational process of downscaling based on assumptions about inter-scalar climate relationships in producing a projection of local and daily weather (which itself acts as primary data in the subsequent crop modelling phase).

What distinguishes one model from another are the assumptions by which observational data and understandings of climate dynamics have been translated into a computational programme. An expanding range of crop models (detailed in Table 3) operate at different resolutions and include and exclude different yield-affecting factors (i.e. they make observation-based assumptions about the significance of different relationships between different soil, land management, crop and climate properties).

Table 3 Details of five crop models

Crop Model	Data Input Requirements				Phenological Stages	Resolution	Yield-Affecting Factors	
	Climate	Soil	Land Mgmt.	Crop			Included	Excluded
DSSAT (CERES-Maize) Jones and Kiniry (1986) Texas A&M University	Radiation and daily temperature and precipitation	Soil albedo, and soil layer thickness	Sowing date, plant density, irrigation schedules	Pre-set crop genetic constants	Germination-emergence - end of juvenile -tassel initiation - end of leaf growth - silking - effective grain filling - physiological maturity	Field to Regional	Radiation, leaf area index and reduction factors for temperature and moisture stress	Ozone damage, pests and disease,
GLAM Challinor et al (2004) University of Reading	Maximum, minimum and mean daily temperature, daily precipitation Does not require spatial downscaling	Soil water content: drained upper limit, lower limit, saturated upper limit	Planting date	Maximum rate of growth of crop leaf area index, change in root length density with change in leaf area index, root extraction front velocity, ... (20 total)	Emergence – leaf tip appearance – leaf collar appearance – leaf senescence Tassel initiation - tasseling – silking – physiological maturity	Large area – commensurate with global and regional climate models	Radiation, temperature and moisture stress	Atmospheric chemistry, fertiliser input, pests and disease, extreme temperature effects
Hybrid-Maize Yang et al (2004) University of Nebraska	Total solar radiation, daily maximum temperature, and minimum temperature, relative humidity, rainfall, and reference evapotranspiration	Max rooting depth, texture, initial moisture status, bulk density	Planting date, hybrid maturity, and planting density, Rainfed/irrigated	'Generic' preset properties – can alter 'growing degree days' for phenological stages'	Germination – emergence – silking – physiological maturity	Field to Regional	Temperature-driven phenological development, vertical canopy integration of photosynthesis, organ-specific growth respiration, and temperature-sensitive maintenance respiration	Nutrient management; weeds, insects, diseases, atmospheric chemistry
AguaCrop FAO (2010)	Daily maximum and minimum air temperatures, daily rainfall, daily evaporative demand of the atmosphere expressed as reference evapotranspiration , and the mean annual CO_2 concentration in the bulk atmosphere	Depth, texture, hydraulic conductivity	Fertilisation, irrigation management, planting date	29 preset variables (no varietal difference)	Sowing – emergence – flowering – maturity – senescence	Field	Water availability/ water stress	Nutrient management; weeds, insects, diseases, ozone damage
GAEZ FAO/IIASA (2000)	Daily solar radiation, daily mean air temperature	Depth, slope, drainage, texture, chemistry	Land Utilisation Type (LUT)	Pre- and post-dormancy periods, maximum leaf area index, crop water requirements, moisture-stress related yield reductions	N/A	Regional to Global	Soil moisture conditions, radiation and temperature,	Soil erosion, CO2 fertilisation effect, and nutrient loading in the soil, and technological development in the future

Identifying Model Uncertainty

The projections of climate and crop models are sensitive to a combination of the input data, applied assumptions and computation processes through which they are produced. This can be seen, for example, in: the sensitivity of climate model projections to the particular climate model chosen to drive it; the sensitivity of GHG emission projections to the assumptions captured within the emissions scenario model; and the sensitivity of crop projections to the input soil data.

Presented in figure 11 are the average daily rainfall projections for 2040-2069 for Kenya across four seasons made by four commonly referenced AOGCMs, based on the same GHG emissions information.

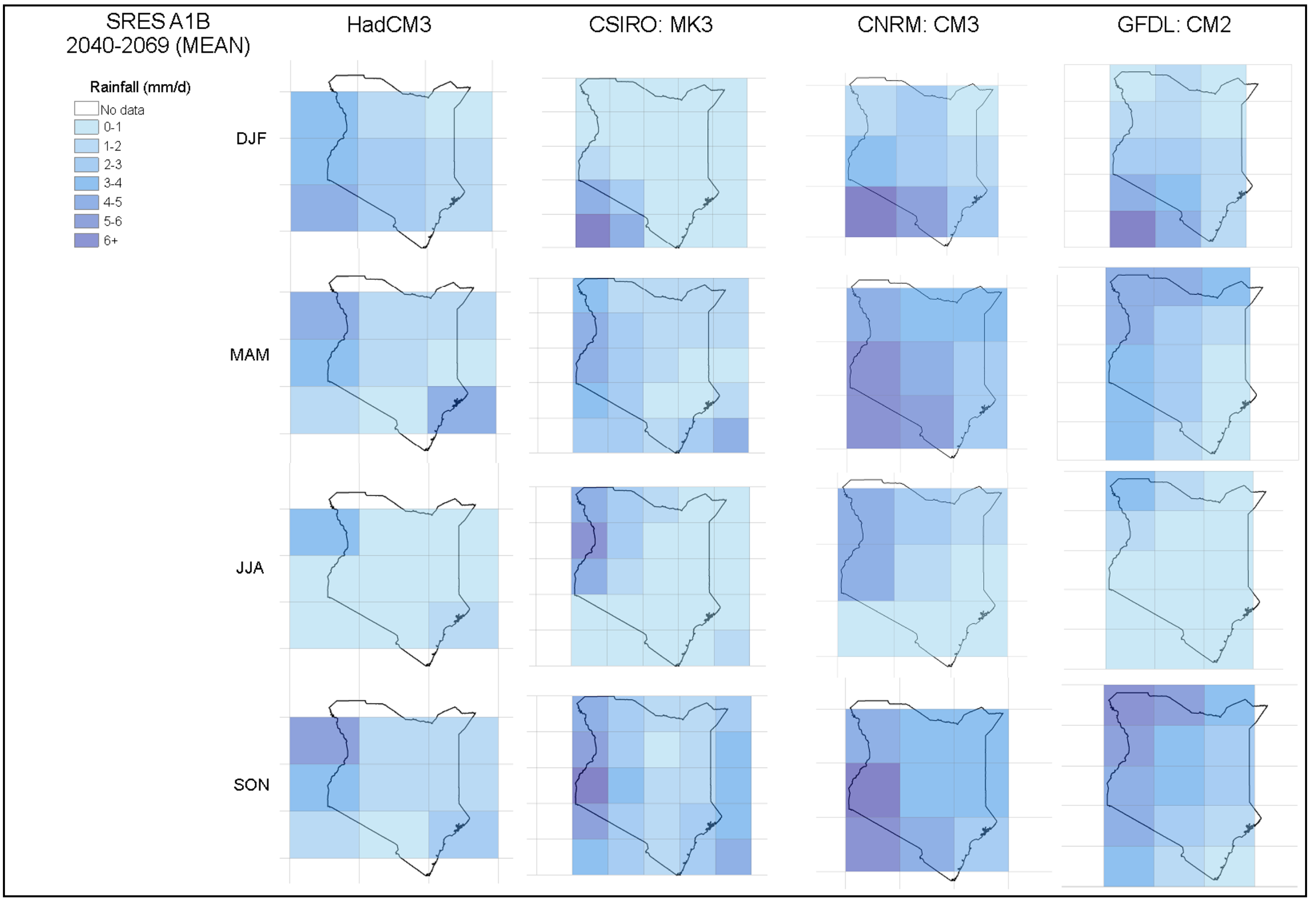

Figure 11 Average daily rainfall projections of four seasons (DJF, MAM, JJA, SON) for 2040-2069 according to four AOGCM model runs based on the IPCC's SRES A1B emissions scenario. Data source: IPCC DDC. The four AOGCM models are : the 'Hadley Centre Coupled Model Version 3' (HadCM3), developed at the UK Met Office's Hadley Centre; the Australia-based 'Commonwealth Scientific and Industrial Research Organisation Mark 3 Climate Model' (CSIRO: MK3); the 'Centre National de Recherches Météorologiques Climate Model Version 3' (CNRM: CM3), developed by the Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique in Toulouse; and the Geophysical Fluid Dynamics Laboratory Coupled Model, version 2 (GFDL: CM2), developed at the NOAA Geophysical Fluid Dynamics Laboratory in the United States.

Horizontal comparison across figure 11 demonstrates the differences in projections by different climate models and highlights the sensitivity of projection data to the assumptions and computations that are represented within the climate model. Different models display different sensitivities to emissions input due to the effect of different assumptions about threshold effects in emissions forcing on the climate system. The effect of these assumptions on the output accumulates over time and, as one climate scientist pointed, out 'is increasingly likely to result in alternative threshold effects in models' (CS4) as projections extend further into the future.

A number of recent studies have also shown the sensitivity of crop model outputs to soil input data (Bert et al. 2007; Pogson et al., 2012; Romero et al., 2012; Varella et al., 2010). Romero et al. (2012) compared the CERES-Maize model results generated from 3404 ISRIC-WISE 1.1 Soil Profile database records, with those generated from a reanalysed and corrected dataset[55]. They found that in 1294 cases, improvements to the input soil data resulted in significantly different yield outputs. Pogson et al. (2012) highlight the particular sensitivity of the Miscanfor crop growth model to constructed soil parameters ('field capacity' and 'wilt point') in water shortage/drought conditions and Varella et al. (2010) demonstrate the sensitivity of the STICS model (Brisson et al., 2002) to a set of seven soil parameters, through a backwards process of generating soil data through the calibration of crop yield observations to model outputs.

It is not just the assumptions of the climate model, the emissions scenarios, and the soil data, but rather all of the points of assumption within the climate-crop modelling chain shown in figure 10 that represent points of divergence and sources of uncertainty in the final model projections.

A popular approach to both calculating and reducing uncertainty is to do multiple runs of a model with perturbed parameters, in order to explore uncertainty in the definition of particular parameters within a model (e.g. uncertainty in the relationships that describe SST-rainfall teleconnections), or runs of multiple models with identical inputs, often described as an ensemble. The cumulative distribution of outcomes in the former case essentially describes intra-model discrepancies, and in the latter the distribution describes inter-model discrepancies. The resultant distributions of outcomes are often considered to represent probability distributions. One climate scientist explained, for example, that 'through ensembles we can

[55] For an explanation of the dataset improvement techniques employed see Romero et al (2012)

verify the robustness of projections and identify the upper and lower limits of change' (CS7), and one respondent on the CCAFS crop modelling survey commented that:

> 'Uncertainty in impact assessments due to the crop model requires better quantification. As has been done for climate modelling this can be done by (i) comparing crop models, and (ii) perturbed parameter simulations for individual crop models.' (CCSur)

On the basis of this same logic, even in the case of the development of the SRES emissions scenarios, there was a whole systematic comparative procedure that aimed to test the robustness and reproducibility of the scenarios of different interdisciplinary teams (Nakicenovic et al., 2000).

However, where there is some level of ignorance or ambiguity within the model outputs, it is a misinterpretation of the result of multiple-model runs to assume that the mean or modal outcome is the most accurate or most likely: 'it would be misleading to simply take the mean' (CS9). In cases where the knowledge gap is largely composed of ambiguity or ignorance, and where ensembles do not explore the full breadth of this knowledge gap, the extremes of multiple model output distributions, and even those values that sit outside of the distribution, may be just as legitimate, and just as likely, as those at the centre. One climate scientist described the process of developing the SRES scenarios, for example, as a 'paradoxical exercise…. [that aimed to] show a scientific consensus about something fundamentally unscientific' (CS6).

The following sections consider the extent to which assumptions within crop-climate modelling reflect ignorance and ambiguity. But, as is revealed, admissions of ignorance and ambiguity, which have important implications for the objectives of climate modelling and the legitimacy of evidence-based endeavours that are built around them, are contentious within the scientific community.

Ignorance about Complex Agro-Climatic Systems

Ignorance represents that gap in knowledge that results from the unexplained, the potential impacts which are not yet identified (let alone ascribed a probability of occurrence). Many climate and crop modellers rightly point out that improvements in observational data are helping to reveal new understandings about system processes, and gradually explaining some of the unexplained; this was clearly identified as a worthwhile and needed effort by the majority of participants in the CCAFS crop modelling survey. Table 4 identifies a number of developments and improvements to observed data sources used in crop modelling studies over the period since 1992 (the period covered by the literature review), most of which can be described as improvements to the resolution, coverage, detail and/or accuracy of datasets, generally facilitated by improvements to data collection capacities and techniques.

Table 4 Improvements in observational data (identified within literature post-1992; see references) across the main stages of the crop projection chain

Observed Data	Main Improvements	References
Emissions trends and drivers	• Better quantification of emissions for disaggregated sources • More accurate monitoring of current emissions • Socio-economic analyses of local, national, and global trends	Nakicenovic et al (2000); Le Treut et al. (2007); Van Vurren et al., (2011)
Weather/climate	• Increasing global coverage of weather stations • Improved accuracy and reliability of data collection equipment (including remote and real-time reporting) • Improved techniques for deriving historical data from proxies	Houghton et al. (2001); Jones et al. (2001); Brázdil et al. (2005); Barnett et al. (2005)
Crop management practices	• Increased number of local-level studies of crop management practices • Participatory approaches to identify locally-relevant trends and drivers of change • National level socio-economic analyses of land management determinants	Gobin et al. (2002); Parry et al. (2004); Fischer et al. (2005); Deressa et al. (2009); Sacks et al. (2010)
Soils	• Increasing global coverage of soil data collection stations • Increased detail in collected data (common collection of more parameters) • Improvements to the temporal and spatial resolution of data sets	Nachtergaele (1999); Dirmeyer (2000); Sanchez et al. (2009)
Crop yield responses	• Increased number of field trials using controlled environments or collecting detailed environmental data • Improved geographical, crop-type, and environmental condition coverage of studies	Thornton et al (1995); Kovács et al (2000); Heng et al (2008); Tingem et al. (2009)

The CCAFS survey results showed that modellers believed that the accuracy of models is 'limited by the availability of location specific data' (Rivington and Koo, 2010: 2), particularly about soils, with 'greater effort in collecting fundamental soils data' selected as the most important way of improving the accuracy of crop model soil inputs (69% of respondents identified this as one of the five most important factors for improving soil inputs). Observational soil data, until recently, has represented a particularly significant source of error in crop modelling due to continued reliance on incomplete and inaccurate global data sets. As Gijsman et al. (2007) explain:

> 'For both the DSSAT and APSIM crop simulation models, for example, a considerable amount of information is required, on either horizon-by-horizon or layer-by-layer basis, which has to be obtained through extensive soil sampling and analysis... There are many situations in which model users simply do not have access to such soil data. In

developing countries, this is probably the rule rather the exception. In such cases, there are only limited options, all of which may involve rough estimates and plain guesses.' (Gijsman et al., 2007: 86)

All of the six reviewed crop modelling projects (see Chapter Four and The Methodology Appendix) use a common source of basic soil data: the FAO-UNESCO Digitized Soil Map of the World (DSMW). The soil map was produced in the 1970s, and although the digitization process has undergone a number of iterative processes, the fundamental data presented in the map remains that which was collected between the 1930s and 1970s (CS8).

New initiatives, such as the global soil map initiative[56], are beginning to improve the availability and quality of observational soil data. The global soil map initiative represents the largest collective attempt to produce a new global map and offer an accurate and usable tool 'to assist better decisions in a range of global issues like food production and hunger eradication, climate change, and environmental degradation'[57]. The five year programme that began in 2009 aims to produce a digital map that offers multiple layers containing details of the functional properties of soil at a 90m x. 90m grid resolution. Newly collected data will be able to feed automatically into and update the map and that the map will also include (updatable) metadata tags describing uncertainty within the descriptive data (i.e. explaining distance from nearest sampling unit or other interpolations to fill data gaps). The Kenya Soil Survey, in conjunction with ISRIC and funded by UNEP, have also produced a high resolution soil and terrain (SOTER) database. The database contains detailed information on soil profile structures, chemical and physical properties of the soil, and information on relief and lithology.

> 'For a long time we have been forced to justify the use of this data set [DSMW], which is a great resource, but is really beyond its sell by date and forces us to make all kinds of inferences on the basis of soil information that doesn't quite offer up a complete description of the growing conditions... I think the academic community has managed to persuade funders of the need for a new and detailed map of global soils.' (CS11)

New initiatives to produce high resolution, detailed and up-to-date information on soil types, will eventually reduce the reliance on extrapolation and assumptions in deriving the soil data input. Similar arguments can be made about improvements in techniques for deriving extended historical climate data from proxies, resulting in improved records of climatic trends and improved understandings of system dynamics (Barnett et al., 2005, Houghton, 2001, Brázdil et al., 2005). Jones et al. (2001), for example, conclude that 'to improve our knowledge of climate

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[56] The Global Soil Map initiative involves a global consortium of research partners: NRCS in North America, Embrapa in Latin America, JRC in Europe, TSBF-CIAT in Africa, ISSAS in Asia and CSIRO in Oceania

[57] Global Soil Map website (http://www.globalsoilmap.net/frontpage?page=4)

history further, we need yet more proxy data: many more earlier data to provide better global coverage and more recent data to enable better interpretation... all of this will help to better define the past and narrow the large uncertainties that surround our present knowledge' (p.665-666).

Whilst CCAFS survey respondents indicated that 'the best way to improve modelling capabilities was to have more and better quality [observation] data for calibration and testing purposes' (Rivington and Koo, 2010: 17), the 'addition of new processes' within models was ranked much lower in terms of its impact on model quality'[58]. However, one climate scientist pointed out that the inevitable result of the increased testing and calibration of models is that 'the number of [model] parameterisations grows' (CS11). Recent modification of the CERES maize code, expressed within the CSM-IXIM maize simulation model for the DSSAT system, for example, sees the addition of new genetic coefficients for the simulation of per leaf foliar surface. Moreover, observations of plant development under a range of ecological conditions and stresses is increasingly allowing for crop models to be run on the basis of location-, condition- and cultivar-specific plant development parameters, rather than generic presets (CS10). As also demonstrated in the development of AOGCMs through the IPCC assessment reports, in the conventional approach to modelling it is clear that, as observational data improves, models, and the modelling community as a whole, becomes more complex.

The ability of models to reproduce observational data is often used as a measure of the accuracy of models, and subsequently the accuracy of their outputs. This can be thought of a process of the crop projection chain in reverse (projection > computation > assumption > observation). Crop model 'verification' often involves a testing of the model's ability to reproduce observed data under specific conditions (i.e. in specific locations for which detailed information about soil, weather and land management have been collected over time). Examples of such studies include: Thornton et al (1995) (testing the CERES Maize model in Central Malawi); Kovács et al (1995) (testing the CERES Maize model under nitrate leaching conditions in Hungary); Heng et al (2009) (testing the AguaCrop model for water scarce conditions in Florida, US and Zaragoza, Spain); Tingem et al. (2009) (testing the CropSyst model in Cameroon); and many more. Similarly, the CSRP at the Hadley Centre has been conducting work, led by Dave Rowell, which

[58] 'Addition of new processes' was identified by less than ten per cent of respondents as the most important factor for improving modelling capabilities compared with approximately 40 per cent identifying 'more and better calibration data' as the most important factor.

analyses the accuracy with which 25 different climate models (used in the IPCC's AR4) reproduce a set of SST teleconnections to African rainfall.

In judging the reliability of models on the basis of their ability to reproduce observed data, as one climate scientist explained, 'you have to assume that accurate reproduction of observations means that the model is fully capturing the system dynamics' (CS1). Whilst this may appear to be a reasonable assumption, it is evident from the CSRP work on teleconnections, for example, that different models are differently able to reproduce different teleconnections. That there are no consistently good or poor performers, suggests that very different conclusions about the accuracy with which models capture system dynamics can be drawn from looking at different sets of model outputs. Whilst a given model may reproduce the connections between Kenyan rainfall and El Niño well, and thus be considered a reliable tool for modelling the future of this relationship, a realisation that it also captures the connection between El Niño and Tanzanian rainfall very poorly (this is the case with several of the models tested as part of Hadley Centre study) may give cause for concern about the extent to which the model really captures the dynamics behind these connections.

The following comment, from one of the CCAFS survey respondents suggests that there are lessons to be learnt from a more lateral look at the successful and unsuccessful simulations of different models:

> 'The community would, I believe, greatly benefit from moving away from 'black box' thinking, whereby crop science knowledge is believed to be contained within models, and towards a focus on interpretation, synergies between models, and an appreciation of the strengths and weaknesses of each model.' (CCSur)

However certain sources of ignorance about climatic and agricultural systems in East Africa have persisted across the modelling community, such as understandings of the relationship between rainfall patterns, ENSO and IOD mentioned in Chapter Two. Other sources of ignorance or disagreement about system behaviour include the parameterisation of cloud radiative properties. The IPCC fourth assessment report refers to a study by Senior and Mitchell (1993) describing the consequences of persistent incomplete knowledge about cloud properties:

> 'They produced global average surface temperature changes (due to doubled atmospheric CO_2 concentration) ranging from 1.9°C to 5.4°C, simply by altering the way that cloud radiative properties were treated in the model. It is somewhat unsettling that the results of a complex climate model can be so drastically altered by substituting one reasonable cloud parameterization for another.' (Le Treut et al., 2007: 144)

These findings allude to a more fundamental issue with the 'complexity logic' – that complexity is prone to chaos. It is widely recognised that climate systems may display chaotic tendencies (i.e. small variable changes create dramatic shifts in the system as a result of complex feedbacks), and the same is true of complex climate models. The problem is that slight discrepancies can produce wildly divergent outcomes.

The persistence of these disagreements, and the inability of models to simulate observations of teleconnections and processes, is indicative of the limitations of models. In relation to crop models, one CCAFS survey respondent highlighted the incompatibilities of a modelling approach with the unknowns of systems and processes:

> 'Current crop models are good enough to predict the effects of changing CO2 concentration and changing climate; however, to calculate actual yields at the global scale for establishing the current and the future global food production, there are many factors involved (yield losses at harvest, infestation by pests and diseases, weed competition, poor soil quality, etc.) that cannot be modelled but will also not be modelled in the future.' (CCSur)

Whilst the comparison of simulations and observations may be the most practical approach to judging the accuracy of model outputs, the legitimacy of the approach depends heavily on the legitimacy of the assumptions on which the evaluation is based. Significantly, in a climate system that is conventionally understood as non-linear and prone to chaotic behaviour, using the ability of models to simulate observed data as a proxy for the accuracy of its projections necessary relies on the assumption that the system dynamics being modelled will continue to display the same behaviour as they have done in the past (assumptions about the insignificance of unprecedented threshold effects). Some would argue that getting the physics of models right, rather than relying on artificial adjustments to simulate observation, will reduce these 'stationarity assumptions':

> 'Models need to reflect the underlying physics accurately rather than relying on calibration. Calibration generally enforces a stationarity assumption, and climate change scenarios always violate this assumption. Only physically accurate models will be useful for climate change.' (CCSur)

But others recognise that 'physical processes can alter across system thresholds' (CS9), so assumptions that systems will continue to operate within certain thresholds into the future, may still be necessary in drawing conclusions about the reliability of projections. Whist increased observations are constantly increasing understanding of agro-climate system dynamics and facilitating improvements in the inputs and resolution of models, there are limits to the extent to which future changes can be known through these models and, as a consequence of these limitations there must be questions asked about the ultimate value of investments and improvements in observation data and model accuracy.

Methodological Choices and Ambiguous Decisions

Differences in outcomes that result from different perspectives (about which it may not be possible to make judgements about legitimacy or about which no one may claim the authority to judge legitimacy) on the subject, reflect the characteristic of incomplete knowledge labelled here as ambiguity. The existence of ambiguities in crop modelling are reflected not only in decisions about how observed data is transformed into projections (methodological decisions), but in the judgements that are made about the accuracy and reliability of the data (e.g. the assumptions made in the reverse production process) and in the relationship between projections and policy, which is introduced here and discussed further in the following sections and chapters.

The result of increases in the complexity of computations and the expanding number of models and data sources, is an ever-increasing number of options in, and approaches to, the whole exercise of crop modelling. ‘Over the last few years, the options available to crop modellers in terms of climate data, farming practice data, soil information, etcetera, have grown so much and the consequence is that project possibilities have just increased exponentially’ (CS23). Evident throughout the discussion thus far are some of the many methodological choices involved in generating a crop projection, choices which are increasing in scope as the various contributing disciplines expand in size and complexity. A selection of those choices, alluded to in the preceding discussion, are summarised in table 5. Methodological choices in relation to greenhouse gas emissions and land management data are expanded on in more detail below.

Projections	Methodological Dilemmas	Sources
GHG Emissions	• Should emissions scenario include/exclude non-energy-based emissions/ natural-emissions?	CS4, CS19
	• Should scenario selection reflect 'most likely' future, be used to assess future interventions, or offer represent best and worst cases?	CS4
	• What are the likelihoods of alternative ideas about population, economic and energy efficiency trends and future policy interventions?	CS4, CS20
	• How should the sensitivity of the chosen climate model to alternative emissions scenarios be interpreted?	CS19. CS20
Climate Projections	• Which models should be included or excluded?	CS1
	• Inclusion/exclusion should be based on what criteria? (e.g. data availability, spatial resolution, capture of ocean-atmosphere flux, dependence on flux adjustments, ability to reproduce observed SST teleconnections)	CS1, CS2
	• What do model ensemble distributions/outliers represent? (e.g. does mean = more likely?)	CS21
Downscaled Weather Data	• What assumptions about the relationship between modelled GCM climates and local observations are acceptable?	CS19
	• Acceptability should be based on what criteria/methods? (statistical significance, local and detailed climate models driven by boundary conditions, identification of key climate mechanisms (indicators))	CS19
	• What spatial/temporal resolution is of sufficient policy relevance?	CS11
	• How should resolution benefits be weighed against interpolation errors?	CS11, CS19
Crop and Land Management Data	• On what basis should land management inputs be determined? (primary data collection, participatory modelling, assumptions about economic rationality, meteorological determinism)	CS9, CS22
	• What should be assumed about future changes in land management practices? (assume no change, socio-economic response functions linked to predictions about socio-economic change, model 'optimal' management strategies)	CS2, CS23
	• What physiology properties should be included/excluded in defining plant characteristics?	CS9, CS11, CS22
	• What level of detail/accuracy about plant physiology is necessary?	CS11
Soil Data	• Which properties should be included/excluded in describing soil characteristics?	CS8, CS23
	• Inclusion/exclusion should be based on what criteria? (functionality, data availability, resolution of available data, statistical significance identified in particular crop studies)	CS8
	• Which soil data sets should be used?	CS8
	• How should uncertainty created by errors in and the resolution and age of datasets be interpreted?	CS8, CS23
Crop Model Selection	• Which crop models should be included or excluded?	CS9, CS22
	• Inclusion/exclusion should be based on what criteria? (e.g. data requirements/availability, computational capacity, spatial resolution, reliance on statistical adjustments, inclusion of crop responses to atmospheric CO_2, necessity of climate downscaling)	CS11

Table 5 Improvements in observational data (identified within literature post-1992; see references) across the main stages of the crop projection chain

Although the SRES marker scenarios are thought to represent the 'best' quantitative manifestation of an emissions storyline, this is not a comment on their probability of occurrence or their proximity to realism. Given the limitations of model predictions, authors have pointed out that scenarios can provide a tool for testing the robustness of adaptation options (e.g. Hulme et al., 2001), but on what basis, then, should climate and crop modellers select an emissions scenario for projecting a future environment that is informative to adaptation strategists and policy makers? It could be argued that the more detailed an emissions scenario model is (i.e. the more emissions sources and drivers of change it incorporates) the more reliable or justifiable is its product.

> 'Calculations of the impact of deforestation and land use on emissions are improving for sure, and including these kinds of things within projections or scenarios of future emissions can only help to make such scenarios more complete... because we are talking about scenarios rather than forecasts, the aim has to be complete capturing of alternatives, rather than accuracy per se' (CS10)

A vast and growing literature on emissions scenarios focuses predominantly, and often solely, on energy-driven emissions. These emissions are described within Figure 12 (circled) using a Kaya identity, which neatly identifies four main sets of assumptions about the future that combine to create a scenario: population size, affluence, energy reliance, and 'cleanness' of energy. However, emissions associated with land use, land use change, and forestry (LULUCF), which is inclusive of agricultural practices and (de/af)forestation (captured by non-energy emissions in the above diagram) as well as land erosion (captured by changes in natural land area emissions – but may be, in part, a positive feedback effect), are increasingly recognised as important drivers of future climates[59] that cannot be ignored within emissions scenarios.

[59] The IPCC fourth assessment (2007) report suggests that land use change contributed approx. 0.5 to 2.7GtC/yr during the 1990s and deforestation contributed 1.6 GtC/yr, compared with roughly 6 to 8 GtC/yr from fossil fuels.

$$\textit{Total Emissions}\begin{cases}\textit{Anthropogenic Emissions}\begin{cases}{}^{\alpha}_{\omega}\textit{Non-Energy Emissions} = {}^{\alpha}_{\omega}\textit{Managed Land Area}_1(\textit{Emissions}_1) + {}^{\alpha}_{\omega}MLA_2(E_2) + \ldots + {}^{\alpha}_{\omega}MLA_x(E_x)\\[2ex] {}^{\alpha}_{\omega}\textit{Energy-driven Emissions} = {}^{\alpha}_{\omega}\textit{Population} \times {}^{\alpha}_{\omega}(\textit{GDP / Population}) \times {}^{\alpha}_{\omega}(\textit{Energy / GDP}) \times {}^{\alpha}_{\omega}(\textit{Emissions / Energy})\end{cases}\\[4ex] \textit{Natural Emissions}\begin{cases}\textit{Volcanic Emissions}\\ \textit{Release from Natural GHG stores}\\ \textit{Natural Land Area}_1(\textit{Emissions}_1) + NLA_2(E_2) + \ldots + NLA_x(E_x)\end{cases}\end{cases}$$

Figure 12 Where α and ω represent lower and upper limits imposed by intervention policies. In SRES emissions scenarios both α = 0 (or - ∞ in cases where negative emissions are possible) and ω = ∞; i.e. they are non-interventional scenarios. MLA_X represents total land area under land cover type x and E_X represents emissions per area associated with land cover type x.

An alternative is to look directly to emissions outputs, rather than the mechanics of the scenario model. The IPCC's fifth report, due for publication in 2014 will utilise Representative Concentration Pathways (RCPs) (four quantitative descriptions of total atmospheric concentrations of GHGs and aerosols) in place of emissions scenarios with the aim of 'shortening the time required to develop and apply new scenarios' (Moss et al., 2010: 751). Such a strategy would allow for the running of 'best and worst case scenarios', a backwards process of selecting the scenarios that produce future climates at the upper and lower extremes, such that both can inform mitigation and adaptation policy making. Without the admittedly problematic probability distribution that fills the gaps between them, however, the usability of this information may be questionable (particularly if the two extremes point to opposing policy responses). Due to ambiguity within the process of developing emissions scenarios, it cannot be known if all possible, or even likely, emissions scenarios are covered. Selecting a scenario for modelling future realities (i.e. for informing adaptation policy) depends critically on the perspective that one takes on the key driving forces behind emissions. Equally subjective are judgements about the likelihoods of alternative emissions scenarios, the framing in or out of emissions driving forces in one's own picture of the future, the justification of upper and lower limits on the total emissions product, and the inclusion or exclusion of policy interventions.

As with emissions data, generating land management input data depends on the subjective construction of a future scenario, a process in which multiple and interacting driving forces of change may be framed in or out and justified on the basis of different values and perspectives.

Across the six projects reviewed, alternative approaches to describing land management practices are evident:

- CERES-Maize may be programmed to automatically generate a planting date once climatic conditions or water availability passes a certain threshold. Jones and Thornton (2003) programmed the model such that the growing season automatically begins after 5 consecutive days of the top 100cm of soil having a water content of 70%, with the growing season ending when water content fell below 50% for eight consecutive days. Other management data, such as planting density, however, is necessarily based on estimates of 'typical' contemporary management in the location of interest, and often with a necessary assumption that the maize is mono-cropped (Jones and Thornton, 2003).
- In a study by Thornton et al. (2009) planting date and density is determined from discussions with key informants, small-scale studies, country reports, and agriculture surveys,
- The Land Utilisation Type (LUT) database developed and used as a model input by Tatsumi et al (2011), based agricultural survey and satellite data offers a geographic description of 'input level' (either high, medium, or low), which describes, amongst other things, capital and labour intensity, fertilisation level, and technological development level (after the LUT definitions of the FAO (1978)).
- Some models (e.g. Parry, 2004, Nelson, 2009) have been developed to incorporate a simulation of changes in land use in response to socio-economic scenarios, this has largely been done through the integration of an economic model that assumes that production decisions are market driven (including the costs of inputs) and defines a set of thresholds in the market profile that produce changes in land management. In the model described by Parry et al (Parry et al., 2004) regional-scale production responds to market changes described in socio-economic scenarios in accordance with the IIASA's Basic Linked System (BLS) world food trade model.

Many studies utilise data on current management practices as input data for crop modelling, and as this data improves in resolution, coverage and detail, the need for certain assumptions (e.g. the assumption that management practices in location A are the same as those in location B, 40 miles away, about which there is published information). The necessity of other assumptions, however, is less readily removed through observational data improvements. In using information for observations of current land management as a direct input into crop models, for example, a key assumption is made about the insignificance or lack of future changes to land management practices (and/or drivers of change). An alternative to making this potentially problematic assumption is to introduce yet another model that incorporates, for example, the impact of projected changes to the socio-economic influences on land management decisions (e.g. Parry et al., 2004, Nelson, 2009). The complexity and large error margins in such attempts, however, reflect the complexity of individual decision making, and themselves require assumptions to be made about the relative significance and likely future direction of different drivers of change. As one crop modeller pointed out, 'assuming rationality in land management is problematic' (CS11), in a world in which there may be alternative or competing rationalities (i.e. those decisions in which yield optimisation is sacrificed in pursuit of other benefits) or imperfect decision making (i.e. decisions made on the basis of incomplete information). A respondent to the CCAFS survey further commented that 'it is not enough to assume that the only adaptation mechanisms that farmers will use are to change planting dates and current varieties; there are many more adaptation options available to farmers' (CCSur).

Of course, it may be argued that certain assumptions are more realistic than others:

> 'An emissions scenario based on the possibility of the invasion of fossil-fuel powered alien spaceships is less easy to justify than one that more closely reflects the status quo' (CS10).

Furthermore, as several respondents pointed out, methodological decisions are often made for reasons of accessibility and availability (e.g. access to particular datasets or models), not just judgements about accuracy. Similarly, methods might be chosen in spite of their flaws rather than in denial of them, because of their virtues. The ability of models to simulate observed data, for example, is commonly used as a proxy for model accuracy because it is the most efficient way of comparing performance across models rather than because of assumptions about its infallibility as a method (CS2). However, deciding on methodological approaches to generating crop projections inevitably involves some degree of subjective choice. Value judgements necessarily enter into a process of framing the limits and determining the drivers of the change that is being modelled, with significant implications for the 'evidence' that the process generates, and how it is interpreted.

Looking across the production chain of climate-crop models, it becomes clear that the projections that they produce are underpinned by a combination of uncertainties, ambiguities and ignorance and, as such, it is misleading to simply present model projections as probabilistic risk assessments, as is commonly done within the conventions of the IPCC for example. As is discussed, particularly in the later parts of this thesis, the existence of ambiguities and ignorance in particular represents points that would benefit from knowledge exchange, negotiation and social learning.In closing down to risk, these opportunities are essentially denied (or alternative knowledge delegitimised). As a precursor to this discussion, the final section of this chapter looks in more detail at the communication of climate-crop projections (and their incompleteness) and their interaction with some of the stakeholders in agricultural adaptation of interest in this research.

Communicating Incomplete Climate-Crop Projections

In March 2012, one of Nairobi's most high end hotel and conference centres played host to a workshop, led by the HFP, Christian Aid, and the Kenyan Meteorological Department, which aimed to bring together climate scientists with humanitarian organisations to promote better dialogue about the on-ground usability of climate forecasts for agriculturalists. Conference delegates enjoyed an opulent buffet lunch at the parquet-floored, leather-furnished, luxury conference centre and participated in discussions centred on how best to communicate to farmers the March, April, May (MAM) forecasts for Kenya, generated by the Kenya Meteorological Department. The forecast is represented in a set of three maps, each of which divides the country, quite coarsely, into about four to ten (climatically homogenous) regions and for each shows either (1) expected two week period in which the onset of the rains; (2) expected two week period in which the cessation of the rains; or (3) a 'tri-variate' description of the total expected rainfall – a percentage probability of total rainfall being above-, near-, and below-normal. One of the key messages of the initial presentations had been that forecasts are probabilistic, and that climate scientists have a responsibility to engage with policy making, speaking clearly about the incomplete knowledge in the predictions.

The presentations were followed by an exercise in which mixed groups of climate scientists and 'forecast users' (representatives of NGOs) were to discuss the policy recommendations for a particular area in Kenya. The forecast for our group's region, the north western Rift Valley, suggested that rains were expected to come in the third or fourth week of March with a 25 per cent chance of above normal rains, a 40 per cent chance of near normal rains and a 35 per cent chance of below normal rains. In response to this forecast, the suggestions of those climate scientists that had earlier emphasized the importance of probabilities, was somewhat surprising:

> 'The forecast is pointing to drought conditions, so perhaps we should recommend to farmers to plant drought-tolerant or early-maturing varieties... and maybe pastoralists should think about destocking' (FN3)

One of the climate scientists made this recommendation and the rest of the group agreed. The suggestion that an uncertain forecast showing that the season is likely to be toward the drier side of normal should be interpreted as a drought warning and require very drastic response on the part of farmers, was the consensus that I was not expecting. However, the response highlighted a challenge that was much discussed throughout the workshop, of how to communicate and act on incomplete projections. Whilst 'closing down to risk' is potentially misleading, there are, of course, practical reasons for presenting projections as probabilistic, particularly in terms of making them comprehensible and of policy relevance. However, as the discussion highlighted, even probabilities are subject to interpretation and there is, perhaps, an inevitable tendency to plan for those scenarios that emerge as 'most likely' within a probabilistic forecast (even if only by five per cent). As such, closing down to risk, or assigning probabilities, becomes a means of legitimising certain narratives of change. In this case, promoting early-maturing varieties represents an evidence-based policy response, legitimised by the assigning of a marginal probability to the likelihood of a drier than normal season.

Through the programmes of the HFP, the CSRP and, increasingly CCAFS, there is a mounting challenge to the long held convention of maintaining a separation between risk assessment and risk management, reserving the former for the objective domain of scientists and leaving the latter to politics. One consequence of this reconsideration of the unidirectional relationship between modelling and policy is that the need for the communication of a single and simple 'best evidence' message from scientists to policy makers is being questioned. Whilst in the conventional approach climate modellers hold a privileged and powerful position in terms of being able to generate evidence and make statements about its quality and reliability, there is clearly a movement towards the democratisation of these kinds of assessments. During a CCAFS seminar on crop forecasting, the presenter, a climate-crop modeller, was asked by an audience member 'at what point will the models be deemed reliable enough to rely on for farmers?', and the response of the presenter, spoke of the problems of maintaining a distinction between assessment and management, in light of the uncertain, ambiguous and incomplete nature of knowledge:

> 'I think we have to learn from farmers about how they use forecast information to learn about how they might use climate change projections. What we know is that with a forecast, whether it is a weather forecast or a seasonal forecast, you are getting indications about what the likely outcome is going to be, but you are never

> going to get an accurate projection. So what one has to do is to have this process where the decisions people make are actually changes from thinking about having optimal information to having sub-optimal information, and therefore actually making decisions that are based on a spread of possibilities and so you need to change the type of decisions you're making to ones that are robust across uncertainty and use the available information to inform those decisions, but not to think that any particular projection is going to give you the exact answers. We're never going to get that perfect set of information, but we're already at the stage where there is some information that is useful and the hope is that a bigger fraction of the outputs of the models become useful.' (Sem1)

The presenter suggests that crop model outputs can at best represent a tool for aiding farmers in understanding potential future scenarios, not objectively revealing optimal strategies for adaptation. In such utilisation, models and model objectives perform a very different function in which adaptation strategies (e.g. different land use options) becomes the primary variable, and the robustness of these strategies tested across a range of potential future climates (or climate scenarios) (Dessai et al., 2009, Conway, 2011). Such application of models may be both sensitive to the limits of model predictions and not presume that climatic systems are the sole determinants of appropriate adaptation strategies. There is a realisation amongst a significant number within the science/modelling community that climate models should not be seen as predictive 'truth machines' (Wynne and Shackley, 1994), but rather should be developed with policy in mind; designed not around creating best predictions of the future, but around making a contribution to particular policy questions – challenging the unidirectional approach of evidence-based policy.

For some modellers, the rationale of separating risk assessment from risk management remains so persuasive that the end use and interpretation is not of initial concern. This respondent denies that ambiguity, believing it possible and appropriate to evaluate the 'goodness' of a model, independent even of an intended purpose and utility:

> 'We build good crop models, and then use them for different purposes, which may include climate change and food security, but also other topics. We do not build models for climate change research and food security purposes alone. A good model stands securely on its own feet.' (CCSur Response)

However, many within the modelling community appear to subscribe to the view expressed by another respondent in the CCAFS survey, that 'crop models need to be linked to their use' (CCSur) and aim to generate information of an appropriate level of completeness. This is the foundation, for example, of the Leeds University project 'End-to-End Quantification of

Uncertainty for Impacts Prediction', which 'embraces uncertainty'[60] and aims to incorporate the 'impacts community' within modelling initiatives in order to determine what we need to know in order to make decisions (and design modelling endeavours as such). For many this means bucking the trend of increasing complexity in models and instead opening up the process of knowledge generation to those stakeholders and knowledge conventionally considered as 'non-expert'.

Whilst complex models undoubtedly produce policy relevant information, they do not hold a monopoly over such information and simpler and non-predictive tools may better facilitate a more participatory and deliberative form of knowledge production and a more plural approach to combining evidence and policy. In the case of the HFP, efforts have been made to develop a system of integrating local indicators of weather within local seasonal projections, and have shown evidence of a greater ownership over, and acceptability of, projections amongst smallholder farmers (Sem1). CCAFS and the CSRP have worked with a range of policy makers and smallholder farmers in determining the most appropriate and useful time scales, resolutions, and crop and land management parameters for models and input information on land management strategies and adaptation options to be modelled. In CCAFS climate analogues work, models are used as a way of identifying linkages for global knowledge exchange (based on the idea of learning from experiences in analogous agro-climates), and CCAFS work on 'climate information for decision making' focuses on identifying opportunities for incorporating model information within processes of social learning for climate adaptation.

Although many of these projects are in their early stages, the endeavour towards a broadening of the use of climate-crop models and their incorporation within more targeted and integrated climate impact and adaptation programmes are indicative of a movement away from the conventions of an expert-monopolised risk assessment that is divorced from the politics of risk management. In Chapter Nine, it is argued that a more systematic and reflexive consideration of gaps within climate-crop modelling knowledge can help to facilitate this movement further, both in terms of its conceptualisation and practical implementation.

[60] www.equip.leeds.ac.uk (accessed: 3/10/13)

Conclusion

The predictive limitations of crop and climate models are recognised and warnings about over-reliance or uncritical interpretation of model outputs are regularly made in crop model literature. However, there is an evident tension between suggestions that these limitations result from the relative simplicity of models (i.e. their inability to incorporate all of the factors that interact in determining the future) and acknowledgements that there is an inherent 'unknowability' about the future. Whilst the former can be addressed through the growth of the modelling endeavour, and is undeniably driving a trend of more science, more scientists, and more scientific complexity in the global project of climate and crop modelling, the latter argument might question the justifiability of such endeavours and investments, and suggest rather that decision-making process that might better utilise the projections within a more integrated, non-predictive, and participatory approach to risk assessment.

The presentation of model outputs as an objective risk assessment and displaying a convincing probability distribution of potential future change, seemingly justifies a focus on increasing investment in model complexity in order to better simulate the reality of the complex agro-climatic system. However, the analysis of the climate-crop model production chain presented in this chapter suggests that incomplete knowledge within and across climate-crop models is not simply represented by risk, but also incorporates uncertainties, ambiguities and ignorance. As such there are limits to the extent to which models can close in on a single reality and there is an evident need for more critical reflection on, and stakeholder involvement in, knowledge production. This need is increasingly realised within climate adaptation projects that have critically analysed the use of climate information and developed innovative ways of designing participatory mechanisms of knowledge production that are centred around negotiated policy problems. The unknowns of climate change and assumptions and narratives about its directionality are an important context for the following chapters, which demonstrate the ways in which experience, assumptions and evidence of climate change are inextricably connected with narratives of future agriculture.

Chapter Six: Smallholder Farming

Experiencing Risk and Internalising Knowledge

In this second empirical chapter, climate change impacts are considered in the context of smallholder farming in Kenya, with a view to building an understanding of how farmers experience, evaluate and respond to uncertainty, not only in climates, but in the multifaceted social, economic, and political systems in which they operate. The process of generating knowledge revealed in this chapter is quite different from that of the previous chapter, but it is similarly dependent on observation and experimentation, as well as assumptions and value judgements to fill knowledge gaps that are equally characterised by a combination of risk, uncertainty, ambiguity, and ignorance. Drawing on a combination of participants' experiences of recent change, revealed through interviews and participant observation, and expectations and plans for the future, discussed in participatory scenarios workshops, the chapter identifies both parallels and distinctions in this contextualised knowledge generating process. Particular attention is given to the role that interaction with others and the communication of information from 'external' actors (development projects, agricultural extension, and agricultural input supply systems) plays in shaping farmers' decisions. Throughout the chapter it is argued that these decisions are historically and socially embedded, personal, and often draw on multiple evidence bases, experiences, and experiments. However, a general theme of scepticism and distrust of external intervention, is evident across the research sites and this is manifest in what is described here as the 'internalisation of knowledge' – a preference for relying on local indicators and on-farm experimentations and a reluctance to implement radical or unprecedented changes, particularly where they involve new relationships of dependence (e.g. with technology suppliers). Again the central research question is addressed through a description of the context of knowledge production in smallholder farming, an analysis of the nature of incomplete knowledge, and a discussion of knowledge exchanges and interactions.

Contextualising Smallholder Farming

The third Nandi/Nyando scenarios workshop took place at a community meeting point under the shade of a large fig tree outside the Nyenyilel Primary School, three weeks after one of the worst storm events that Joyce could remember experiencing in her life, had stripped the leaves off her maize stalks and felled small areas of her two acre plot. 'We have not received those kinds of hails for more than thirty years in this place… we could not have expected this' she explained to the group. The storm, which was still evident in surrounding fields of shredded maize plants, came two weeks before Joyce was intending to harvest, and the continued inclement weather that followed left her concerned about water damage and rotting of the crops in the field, and facing potential difficulties in drying the maize kernels for storage. It was a story that was common to many of the participants and the consequences of a lost harvest – the challenges of food provision and paying school fees – which were similarly recounted with a familiarity that suggested both a common dependence on the maize harvest across the group and a recent experience of crop failures, showed too in the intensity with which farmers monitored their drying maize kernels and rallied around to lay it out and gather it in during almost any window of dry weather.

The context within which smallholders in both Nyando/Nandi and Makueni manage their maize production can be characterised as one of constraint. Particularly in the dry mid-altitude agricultural environment of Makueni, rain-fed production is inevitably limited by water availability; severe low rainfall seasons in 2009 and 2010 and associated crop failures are fresh in the memory of farmers in Makueni (M2, M6, M15). In the case of Nyando/Nandi, these constraints take place at either end of the scale, with heavy or untimely rainfall equally representing a cause of crop failure, as it had done in 2012 (N14, N27, N28).

In both cases, it is not simply quantities of rainfall that are a challenge for farmers, but it is the unpredictable nature of seasonal weather that makes preparation so difficult and exacerbates vulnerability. Whilst most farmers received frequent short term (3-5 day) forecasts of weather through radio broadcasts, very few accessed seasonal projections and a number of farmers in Nandi in particular, pointed out that forecasts were regional as opposed to local and, as such, were often uninformative or inaccurate (N7, N18). A lack of access to information, not just about climates, but also in relation to new agricultural technologies and techniques or market opportunities, represents an important aspect of the context within which farmer choices and decision making are constrained.

Options for agricultural change are, of course, limited too by economic constraint. The unaffordability of market fertilisers for farmers in Nandi-Nyando ties many farmers into dependence on the uncertain supply of government-subsidised fertiliser and in Makueni many smallholders lack sufficient resources to purchase commercial hybrid seed varieties. A particularly high food security and livelihoods dependence on maize and little (or no) off-farm income, for the poorest subsistence farmers, mean that these farmers can neither afford to invest in change nor afford the risk of such change being unsuccessful. Ifejika-Speranza et al.

(2008) have noted, for example, that 'the poverty-driven inability to adopt risk-averse production systems' (p.220) locks smallholder farmers into low-input maize production and, consequently, creates climate change vulnerability.

More information on recent changes in agriculture in the two regions is presented in the following section, but it is notable that in the recent history of both districts there is little evidence of opportunity-driven changes in maize farming. A reluctance to take advantage of market opportunities (such as in the growing of cash crops that some farmers in Makueni pursued), reflects a lack of investment capacity; social and cultural values (Adger et al., 2009); and may be exacerbated by lack of reliable and trustworthy information about such opportunities.

However, to describe the context solely as one of constraint is both to deny significant variation in the resource capacity of smallholder farmers in both regions and to overlook resourcefulness and social capital that is created through (multi- and inter-generational) knowledge and resource sharing between family members, neighbours and friends. Learning and information and resource exchange was evident in all of the research locations, in observations of communal approaches to maize drying, as well as shared land preparation and harvesting activities, food sharing, farmer community group meetings, as well as in the interactions that took place within the participatory workshops of the research.

The second Makueni workshop was largely dominated by women, both in terms of numbers and strength of opinions and personalities. In this workshop, a number of women talked about the need for utilising soil and water conservation techniques. A local councillor, who clearly commanded respect amongst the group, pointed out that approaches such as irrigation or terracing would require significant technical training and financial investment (MW2), but another woman, who had made quite a number of changes on her farm in recent years and is seen as fairly innovative and successful farmer within the community, explained that she had been practising simple water harvesting and irrigation techniques and argued that these could be widely adopted. Several participants expressed an interest in learning more about the equipment that she used for rainwater harvesting.

Similarly, there were farmers that had begun make their own compost, from farm and household waste, in some cases quite ambitiously within large purpose-built pit structures, in order to reduce their reliance on chemical fertilisers, and for application on vegetable plots. A young man was even making his own top-dressing fertiliser from the leaves of a perennial plant that grows locally. Several farmers in Kipkaren had been taught the techniques of composting and making fertiliser by a neighbour that had attended a course provided by a local NGO. The training received by the young men had been supplemented by their continued observation of the success of the methods on their neighbour's farm, and this had given them the motivation to adopt the same practices.

Actors other than smallholder farmers play an important role in shaping adaptive capacities and the contexts within which smallholder farming operates. In Kipkaren (in Nandi) for example, an NGO-run agricultural training centre plays an important role in facilitating learning and sharing information about new agricultural technologies and techniques. Agricultural extension workers, agrovets, agricultural shows, research organisations, crop breeders, charitable organisations, and other community groups (such as those detailed by the CCAFS village baseline surveys and listed in figure 6), all interact with smallholder farmers in different ways and to different extents; in some cases as salesmen and in others as information providers or even knowledge brokers. The nature of knowledge sharing and shaping that takes place through these interactions can be a means of both building adaptive capacities and closing down options for agricultural change. These interactions and opportunities for knowledge sharing are described and discussed in more detail later in the chapter.

The next section focuses on the nature of knowledge that is generated within this context and it describes smallholder farmers' experiences of uncertainty and ignorance and the ambiguous choices that they make in managing and maintaining their farms and livelihoods. Climatic, socio-economic, and information constraints, as well as relationships with others, inevitably come to shape both these experiences and the choices that are made in response.

Pathways of Change and the Nature of Knowledge in Smallholder Farming

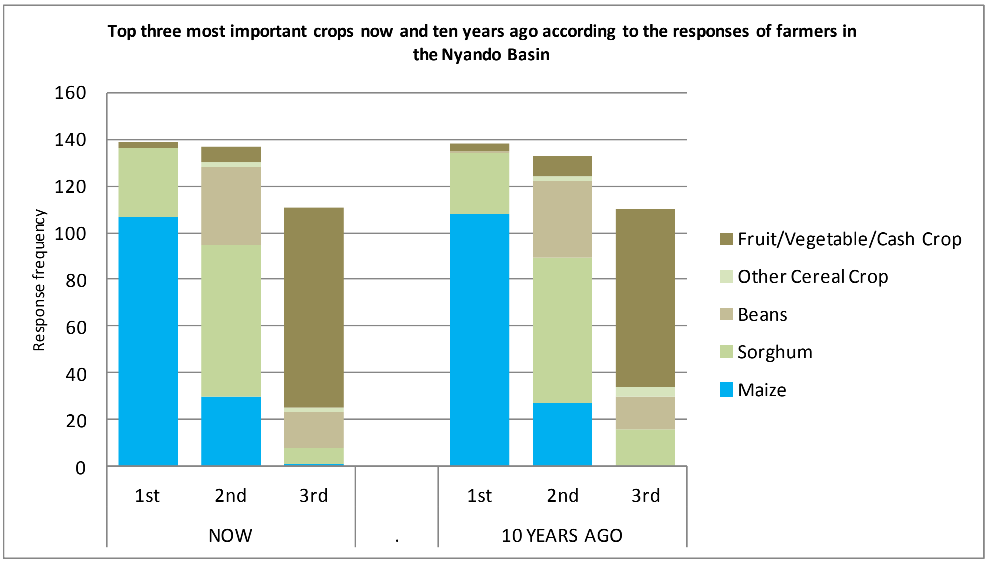
In order to draw insights into the nature of incomplete knowledge within the context of smallholder farming, the analysis presented below focuses particularly on decision-making in, experiences of and approaches to four main categories of change in maize farming. Discussions about experience of recent challenges and opportunities in maize farming and scenarios workshops alike were structured around the following four categories:

- Status quo
- Changing land management, preparation and inputs

- Adopting varieties and technologies
- Alternatives to maize for market and home consumption

Prior to the analysis of uncertainty, ambiguity and ignorance within these agricultural changes, a description of the nature of maize farming in both regions is described with a particular emphasis on contextualising and describing what these categories of change represent in the two main research locations. This description draws on information from the CCAFS baseline household surveys, farmer interviews and participant observation.

Differences in recent experiences of agricultural change and the potential options open to farmers partly reflect differences in the constraints described above. However, CCAFS survey data suggests that in both districts, maize has remained as the primary crop, with little evidence of change in its relative importance over the past ten years in either location.



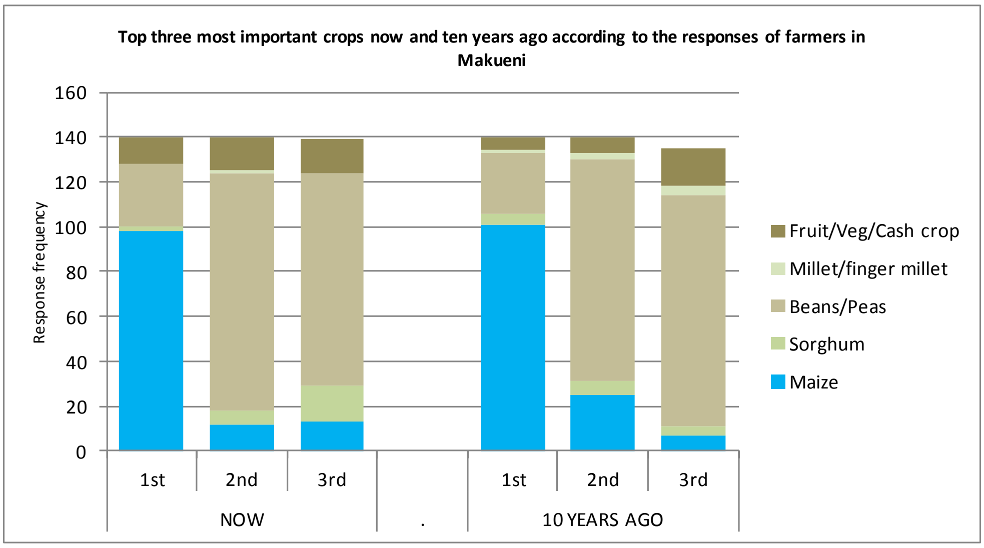
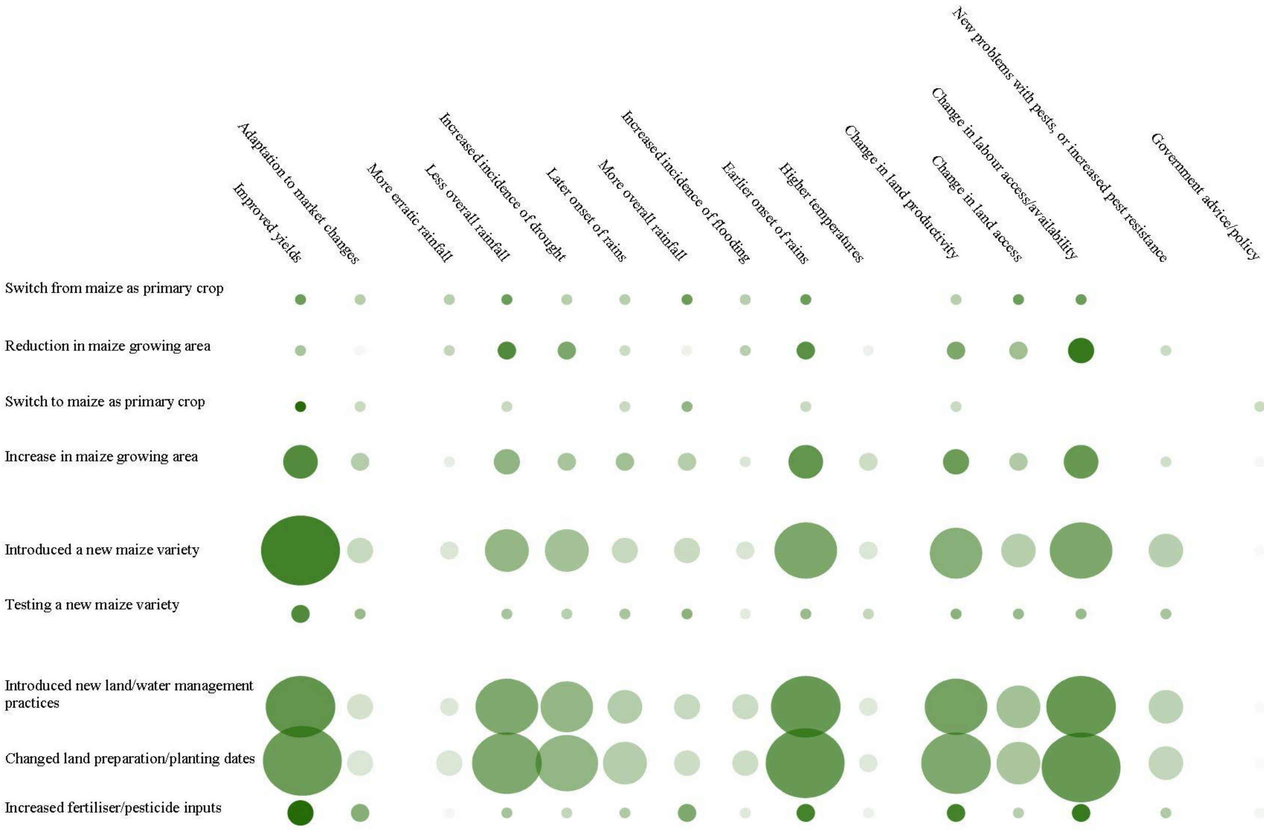


Figure 13 Graphic representation of the top three most important crops grown both current and retrospective (10 years ago) in Nyando Basin (above) and Makueni (below), based on a CCAFS household survey of 140 farming households in each district.

There are noticeable differences in the crop profile, particularly for the second and third most important crops, between Nyando and Makueni, but both display a very stable profile over time, suggesting that there have been few significant changes, and little evidence of a movement away from (or towards) maize farming in either region. However, changes within maize farming, such as the adoption of new varieties and the alteration of land management practices have taken place (N2, N3, N6, N10, M4, M8, M9). Moreover, these changes are made in response to a range of factors not restricted to climate, but also inclusive of push and pull factors from markets, policies and other agro-ecological changes (such as pests) (N2, N6, N18, M4, M8).

Figure 14 illustrates data collected as part of the CCAFS survey. Data on maize farming in particular has been extracted and an attempt has been made to link common changes in maize farming over the past ten years to common reasons given for making changes by participants in both Lower Nyando (green chart) and Makueni (red chart). The size of the circle represents the number of respondents citing that combination of change and reason, and the darkness of the shading represent the percentage of respondents citing a particular change that also cited the corresponding reason; as such it provides an aggregated picture of the most commonly linked changes and reasons.



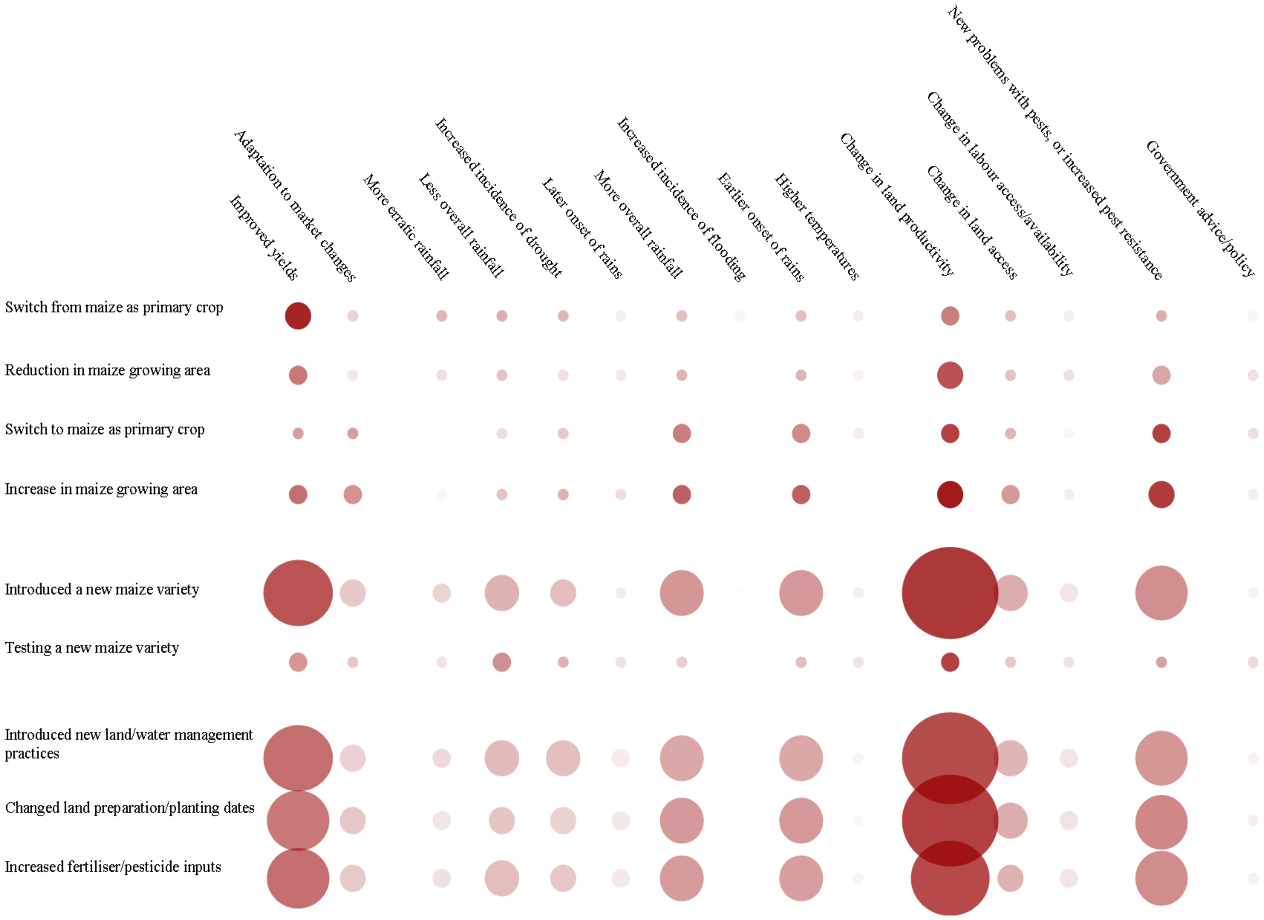


Figure 14 Graphic representation of the main changes in maize farming over the past ten years in Makueni (red) and Nyando Basin (green), based on a CCAFS household survey of 140 farming households in each district. The size of the circle represents the percentage of respondents citing that combination of change and reason. The darkness of the shading represents the percentage of respondents citing a particular change that also cited the corresponding reason. Details about how these graphics were created are available in The Methodology Appendix.

In the Nyando Basin, 'improving yield' was a common motivation for change, particularly the introduction of new maize varieties, but changes in rainfall and labour availability were also cited by a number of farmers and often linked to changes in land management, particularly changes in planting and land preparation dates as well as changes in water management practices. The data suggests that over the past ten years responses have been made to both earlier onsets of rains as well as lower overall rainfall. Government policies and advice have apparently had relatively little impact on maize farming in the district. In Makueni, the most commonly cited reason for changing maize farming was a 'change in land productivity' and it is common for farmers to introduce new maize varieties as well as change land preparation and planting dates. Government policies and advice seems to have a similarly low impact, and climatic changes have also apparently had relatively little impact on maize farming practices compared with changes in land productivity.

Farmer interviews and scenario workshops provided further information on the experience of different types of change. Different ideas of what a 'changing land management, preparation and inputs' narrative might involve in the two regions were drawn out within different groups reflecting differences in familiarity with techniques and their appropriateness for the agro-ecologies and markets in particular locations. In Makueni district, participants in the first workshop identified the use of water and soil conservation techniques, such as zero tilling and terracing, as components of a viable narrative of change (MW1, MW2). In Nandi/Nyando, participants in the second workshop discussed the benefits of growing short-cycle maize during the short rains season (NW2) and replacing chemical fertilisers with manure and homemade compost (NW2).

Other than seed varieties, technology adoption was seen as an irrelevant narrative of change for many smallholder farmers because of the perception of high initial investment costs, which, even in an uncertain future, it was difficult to perceive as being overcome. A larger scale (8-10 acre) farmer in the third Nandi/Nyando workshop expressed interest in investing in mechanising planting and harvesting (NW2), but other participants were quick to point out that this was not a viable option for many of them. A young farmer from Kipkaren explained that farmers in his area are interested in low-cost and testable technologies, such as those that might reduce post-harvest storage losses (NW1). In Nandi/Nyando, for example, an NGO had promoted the use of weevil- and rat-resistant maize storage bags and a number of farmers had purchased a small number of bags to trial in their stores.

The adoption of improved varieties of maize was identified as a key component of this narrative in both districts. Multicriteria maize selection exercises were undertaken in which participants were asked to each assign a total of ten beans across thirteen positive characteristics of maize[61], in accordance with their own evaluation of the most desired characteristic profile. Participants were asked to assign beans to as many or few characteristics as they choose, with the number assigned to each representing their relative perceived importance (e.g. if insect resistance was the only characteristic important to a farmer they might assign all ten beans to that characteristic). 'High yield' consistently came out as being a 'high'[62] or 'very high'[62] priority across all of the groups, perhaps unsurprisingly given that many of the other characteristics indirectly benefit the farmer through their effect on net productivity (on which yield has a very direct effect). 'Affordable seed' on the other hand, was consistently a 'low priority'[62], suggesting that, for the most part, participants are willing and prepared to pay more for a variety that meets their desired characteristic profile. Although very few participants from Nandi/Nyando suggested that they are currently willing to invest in more expensive seed that is currently on the market (e.g. Pannar619), this was not necessarily due to the cost of the seed, but due to a combination of the lack of availability of the seed and a lack of evidence and experience of their benefits (NW3). Drought tolerance was consistently identified as a high priority by participants from Makueni, but ranged from 'high priority' to 'low priority' across Nandi/Nyando groups. Those groups identifying it as a high priority within Nandi/Nyando explained that they desired a maize variety that they could plant in the short rains season in order to realize a two season crop.

Few respondents had experience in growing alternatives to maize either for market or home consumption and a number of participants identified the importance of maize to the diets of their families and the necessity of being able to produce their own for reasons of food security (MW1, NW2, NW3). However, there were some examples of commercial production of cash crops in Makueni, particularly fruit trees and sisal. A woman in the second Makueni workshop said that she had already begun along a pathway of alternatives to maize through the commercial production of cash crops (MW1, MW2). She explained that she had been frustrated by maize farming and she had seen some demonstrations of fruit tree farming at agricultural shows and felt that there would be a good market opportunity for them. Others in the groups

[61] The characteristics were determined with the participation of farmer groups and were: drought tolerant; strong stalk; white colour; early maturity; large cob; high yield; medium height; insect resistant; sweet taste; flood tolerant; tall stalk; tight husk on cob; affordable seed.

[62] Priority classifications are based on the total percentage of beans allocated to a trait by the whole group: 'very high priority' = 50% or more of beans allocated; 'high priority' = 20-50%; 'very desirable' = 10-20%; 'desirable' = 5-10%; 'low priority' = less than 5%

had taken similar ventures. However, an older woman made the point that many of the farmers in the area could not afford the initial investment that some of these alternatives to maize required, she explained that if she wanted to start growing fruit trees, it would require her to clear land, purchase saplings and set up an irrigation system, and eventually have the additional costs of taking produce to market, all of which made it an unviable option. Similarly in Nandi/Nyando there were a combination of experiences of and aspirations to move away from maize towards alternatives that were seen as commercial endeavours, particularly sugar cane, vegetables and, in one farmer's case, tree saplings. There were also farmers experimenting with growing finger millet and sorghum as alternative cereal crops and some that had aspirations to convert to poultry or dairy farming, but most saw the initial investment into infrastructure and feed as the main constraint in adopting this narrative of change (NW1, NW3).

Table 6 summarises the main components of each category of change relative to each of the districts of focus in this study. These components of change are the main focus points of the following presentation of farmers' stories and analysis of incomplete knowledge in the context of smallholder farming.

Table 6 Main components of each category of change in maize farming for Makueni and Nandi/Nyando, based on CCAFS household survey results and primary data

	Makueni	Nandi/Nyando
Status Quo	• Rain-fed maize (both hybrids and local varieties) for market and home consumption • Tilled land, low fertiliser input • 2 short seasons	• Rain-fed maize (most hybrid varieties) for market and home consumption • Tilled land, fertiliser input • 1 long season
Changing Land Management and Preparation	• Changing planting times in response to changing seasons • Water and soil conservation techniques	• Adopting conservation agriculture • Introduction of a short rains maize crop • Reducing reliance on chemical fertilisers • Changing planting times in response to changing seasons
Adopting New Varieties and Technologies	• Adoption of high yielding, drought tolerant varieties	• Adoption of high yielding, insect resistant and drought tolerant varieties • Low cost technologies for effective post-harvest storage of maize
Alternatives to Maize for Market and Home Consumption	• Commercial production of cash crops (fruit trees, vegetables, sisal)	• Commercial production of cash crops (vegetables, sugar cane, tree saplings) • Alternative cereals (sorghum, finger millet) • Commercial production of chicken or dairy (maize grown as feed and for home consumption)

Experiencing Uncertainty in Climates and Inputs

Farmers experience climatic uncertainty at seasonal and sub-seasonal scales and often face the challenge of interpreting multiple sources of incomplete information about upcoming weather. Predicting rainfall patterns in order to determine when to plant and harvest can make the difference between a successful maize crop and a failed one. The challenge faced by farmers in Nandi/Nyando is to make sure that they do not plant so early that seeds get scorched in dry soils before the rains arrive or the plants mature too early (before the rains have ceased), but also to not leave it so late that heavy rains wash away newly applied fertilisers and waterlog the seeds (N9). A combination of short and long-term weather forecasts, including basic probabilistic estimations of their certainty, that are broadcast over the radio from the Kenya Meteorological Department provide important information to farmers, but as Peter Mburu (N7), from Ndalat (Nandi), pointed out 'sometimes it can be right, but other times they are wrong... the weather in this area can be very different to the surrounding areas'.

In the 2012 growing seasons, for example, farmers had received a number of warnings, via agricultural radio broadcasts, that the onset of the rainy season was likely to be late; as late as early May according to the accounts of some respondents (N11, N27). In reality, the area received two false onsets of rain in February and March, isolated rainfall events that were forecast at short notice, but were not followed by sustained rainfall. This came instead in mid-April. Some farmers in the region had responded to these early rainfall events by planting seed ultimately too early and some misread the mid-April rains as another false onset and were slow to get the fields planted.

The uncertainty that farmers experience is not limited to climatic change and variability. The availability, cost and performance of agricultural inputs, such as seeds and fertiliser are also highly uncertain for smallholder farmers. Joyce Cherotich (N4) identified the rising cost and availability of inputs as a major challenge of maize farming in Kipkaren (Nandi/Nyando). DAP fertilizer – of which Joyce's seed supplier, the Kenya Seed Company (KSC) (from whom she buys certified hybrid maize seed each year) recommends that she applies 75kg to each acre of soil prior to planting – can be obtained from the Cereals Board at a subsidised cost of 2600 Kenyan Shillings (KES) (approx. 30 USD) per 50kg bag. However, in two of the past three years (2010 and 2012), due to short supply (which she suspects results from over-exportation) Joyce has been forced to buy it on the market at 4000 KES per bag to avoid the late planting that many of her neighbours were forced into. Instead, and because of the cost, Joyce opted to apply just two bags of fertiliser to her two acres, rather than the recommended three bags. She explained that because the rains are unpredictable and changing, timely land preparation and planting is crucial, 'you have to be ready when the rains come'. Those who were forced to plant late in 2010, suffered when, having missed out on germination during a wet April, the rains ceased for a time in May and June.

In 2011, John Kibete (N5), from Kipkaren in Nandi District, bought government subsidised DAP fertiliser and certified hybrid seed from a local agrovet, however, having paid for the fertiliser in February, John had to wait until the end of April (and spend several days queuing at the suppliers along with hundreds of other farmers) to receive his fertiliser. A small number of farmers in John's local area has recently begun composting in an attempt to reduce their reliance on fertilisers, but he explained that it is very difficult to produce large enough quantities of compost for most maize farmers and that farmers are mainly using compost on small vegetable plots.

John also believes that the seed that he purchased at the agrovet in 2011 was 'fake', and that it had been falsely packaged by the agrovets as certified hybrid when it was actually poor quality seed, resulting in much of it not germinating or performing very poorly. In 2011, due a shortage of KSC hybrid 6-series maize, the mid to high altitude long duration varieties that are commonly grown in the Nyando and Nandi districts, a number of the farmers had been forced to purchase the H520 (from the hybrid 5-series), which is for mid altitude regions and has a shorter growing cycle. Participants in the second Nandi/Nyando workshop pointed out that fake seed on the market and a lack of availability of appropriate varieties continues to be a big problem for farmers and that 'no one is able to prevent it' (NW2).

In response to the uncertainty of climates and agricultural inputs, farmers are practising a number of ways of experimenting and generating knowledge on which to base decisions about changing land management and preparation and adopting new varieties and technologies, including the development of personal weather forecasting systems based on local indicators, establishing on farm trials for conservation agriculture techniques (minimum tillage, mulching, crop rotation), saving local variety seeds, and experimenting with different varieties.

Peter, a farmer from Turbo, explained that there are a number of local indicators of when a weather front is moving in from the direction of Lake Victoria and that these can be used to recognise when the long rains are about to begin. During March and April, Peter keeps a close eye on the night sky, getting up a 4 am each day and noting the clarity of the atmosphere –

increases in the number of visible stars, he explains, is one sign that the rains will be on the way soon and strongly westerly winds are another early indicator. He also explained that lightning and the build-up of clouds in the direction of Mt Elgon are near-term indicators that they will receive rain in 1 to 3 days. Peter's mother added that there are signs that show whether it is going to be good season or not. She described a *'lamoyet'* bush that bears berries early in the rainy season and explained the more berries it produces the better the season will be, for example.

Other farmers in the area described a variety of combinations of the indicators they utilise in interpreting weather patterns and those that they discount as myths (N3, N27). Whilst some farmers felt that these indicators were becoming more important as the weather patterns for the area are becoming increasingly variable (N21), others pointed out that this was making such indicators difficult to interpret (N21, N26), and Peter and his mother felt that knowledge of local indicators and how to interpret them was being lost from the community as they were no longer taught and practiced as they were in past generations (N21, N26, N27). In contrast to Peter's approach, Solomon (N12), a 42 year old farmer from Turbo, like many other farmers (N3, N7, N9, N15, N20), simply plants on the same date every year and hopes that the rains will come. 'Only God can know when the rain will fall' he explained.

Changes to land management and preparation, and particularly the adoption of conservation agriculture techniques in order to reduce tillage and dependence on high quantities of fertiliser, is one option available to farmers, although its success may be dependent on other inputs as well as on (uncertain) rainfall. In 2011, David, a smallholder farmer from Nandi, attended a workshop being run by the local agricultural training centre on 'Farming God's Way'. Impressed with the evidence presented by the God's Way 'champions' at the workshop and on the understanding that the initial labour intensity and input costs that the method entailed would reduce in the following season (as, in theory, the spacing, hole digging and purchasing of mulch would only need to be done once), David dedicated a small half acre plot within his compound to trialling the method for himself in the 2012 growing season. After harvesting the first trial of 'God's Way' maize, he was reserving judgement on the method – the initial costs had been high, good mulch in particular had been difficult to come by, and the returns had not lived up to expectations – he felt that planting seeds within dug holes (as opposed to his usually approach of ploughing) combined with heavy rains right through the growing season (from April to September) had resulted in water-logging and sub-optimal growth. Furthermore, the mulch layer had not been as effective in preventing weeds as he had hoped. David recognised, however, that this was just one year with one particular climate and he felt that at least another two years of trialling and self-evaluating the method would be needed before deciding whether or not to adopt it over a greater area.

Just as in the case of changing land preparation and management practice, the adoption of new maize varieties, particularly in the case of switching from local varieties to commercial hybrids, is a change that is associated with significant uncertainty. Simon Mburu (M6) (aged 48 from Kathonzweni in Makueni District) produces and sells his own seed from a three acre plot of 'local variety' maize, from which he saves approximately 150kg of seed (30kg of which he replants and 120kg which he sells to neighbours for a total of approximately 4200 KES). 'It is difficult to match the certified [maize] from [the] Kenya Seed [Company]' he admitted, 'but the farmers here cannot [afford to] buy those varieties'. In past years, his yields have been low and he has had very little surplus seed to sell. In 2008 and 2009 he had no surplus and only produced enough maize for his family to eat for 4 months, making his casual labour income essential. Simon said that, in the future, he would like to purchase certified seed so that he can have enough maize to feed his family. He believes that this would enable him to get 36 bags of maize from his three acre plot instead of 21. Although some farmers from Makueni district that were using local varieties recognised that the commercial hybrids may perform better, they pointed out that in drought years they are likely to fail just the same and that, as such, there is a risk involved in investing in these more expensive varieties (M1, M2, M7, M8).

Nancy Chepchumba (N25) (aged 41 from Mutwot in Nandi District) is one farmer who has made the switch from local varieties to commercial hybrids. Every year, in February, she purchases certified hybrid maize seed from the Kenya Seed Company (via the local agrovet), but can remember a time, approximately ten years ago, when she would grow local varieties, do some of her own cross-pollinating, and save seeds from the best performing maize plants, for the following harvest. She explained that the hybrid corn, which she grows now, becomes infertile and so it is not possible to save the seed, but she feels that the certified seed gives a more consistent harvest. Nancy said that, for her, the weight and size of cobs is the most important characteristic in maize, with resistance to wind damage (i.e. the strength of the stalk), and the tightness of the husk coverage on the cob being secondary, but important, characteristics. She explained that she also likes the maize to have strong and tall stalks so that it will provide a good source of fodder for the three cows that she has on her compound. Over the past ten years, Nancy estimates that she has tried five or six different maize varieties in her three acre plot and through experimentation and trial and error she is continuing to learn about which varieties are best for her. She explained that in the past she has switched to new varieties because of dissatisfaction with the previous year's harvest or because she has seen a particular variety performing well on a neighbours farm. She often discusses and argues with her friend from a next door farm about which maize varieties have which properties and this comparison and discussion is a key component of the Nancy's own evaluations of the seed. However, she has also had to switch varieties because of the availability of seed at the agrovet. In 2011, due a shortage of KSC hybrid 6-series maize, the mid to high altitude long duration varieties that are commonly grown in the Nyando and Nandi districts, Nancy had been forced to purchase the H520 (from the hybrid 5-series), which is for mid altitude regions and has a shorter growing cycle. She felt that the maize grew well, but did not yield as high as her preferred 6-series. She also recognised that every year the growing conditions are different and so it can be very difficult to compare the performance of the seed. However, she has come to some of her own conclusions about the different varieties: H6213 grows taller than H614 and has a stronger stalk and stronger roots; H614 and H629 have tight husk coverage of the cob, protecting it from insects and water damage; H629 is sweet; H628 gives a high yield. Nancy admitted that her experimentation with varieties is far from systematic, but she feels that it is an important process in optimising the productivity of her farm. She is hoping to plant H6213 next year, if it is available, but feels that she will continue to keep trying different varieties until she finds the right one.

Farmers in both districts recognised the potential yield and performance advantages of commercial hybrid seeds over traditional local open pollinated varieties, but they also experienced the risks of being dependent on seed supply systems that occasionally fail (such as in Mutwot in 2011) and having to invest in seeds that may not perform well. Determining the best varieties for a particular farm often involve experimentation and learning through experience. Farmers in both districts actively seek information through the attendance of field days and agricultural shows. However, many respondents expressed that they wished to see a variety be successful in the fields of their neighbours and even generate their own evidence and experience of the new technology through small plot trials over a number of seasons (N4, N5, N6, N14, N16, M2, M3, M7). The extent to which farmers are able to carry out and evaluate these systematic trials, of course, depends on the size of their land holdings and the accessibility of seeds or other resources, which, particularly in the case of commercial hybrids, may be out of their control.

For the most part, changing land preparation and management and the adoption of new varieties by farmers is done incrementally, such that they can generate an experiential knowledge base on which to make judgements. Farmers who understand the mechanics of maize growing and experience of the operations of maize input supply systems and markets, have a good sense of what the potential outcomes of subtle changes might be, even if it is not possible to make *a priori* probabilistic assessments. In the case of alternatives to maize, however, there may be a good deal more ignorance when it comes to plant phenology and sensitivities to local climates as well as markets and input supply systems; this is discussed in the following section.

Ignorance about Alternatives to Maize

Because knowledge about agricultural changes is generated through a combination of farmer experimentation and observation, as well as external advice and information, there remains significant levels of ignorance about changes for which there is little precedent in the local area, and this ignorance is particularly sustained in situations where opportunities for knowledge exchange outside of farming communities (e.g. through agricultural extension workers) are restricted. A participant at the first Nandi/Nyando workshop made the point that he knows how to grow maize, how to harvest it and how to sell it, but does not have the necessary knowledge to make a success of other crops or farming systems (NW1).

For many of the farmers participating in this research, very little is known about alternative crops to maize, both in terms of growing and marketing, as a potential pathway of change. Moving away from the farming that is well known and practiced is seen as risky for a number of reasons, not least that it brings farmers in to a new set of relationships and dependencies on markets, suppliers, and extension workers, in which there may be little trust and, of course, alternative production systems are vulnerable to uncertain futures of their own. Such risks and the imperative to provide food for the household, for many farmers, trumps alternative goals of adaptation, such as increasing marketable production (Adger et al., 2009).

A young man participating in the first Makueni workshop explained that he currently plants DHO4 maize, an early maturing variety (75-120 days) for semi-arid agro-ecological conditions; however his maize yields are consistently limited by low water availability, ranging between a good harvest of approximately 11 bags (90kg per bag) per acre to the drought hit yields of 2-3 bags per acre. He usually aims to plant two maize crops per year (the first in April and the second in October), but he explained that it is common for at least one of these crops to be hit by water shortage in any given year. 'Sometimes' he said 'the October rains just do not come'. Despite these low returns, however, he believes that it is important for the food security of his family that he maintains a small maize plot (even in those years that it is only enough to sustain the family for a couple of months). Although he understands the challenges of maize farming in the area, he weighs it against the risks of not producing maize and having to rely on markets to meet his family's food requirements and chooses to mitigate the risk of food insecurity by internalising the responsibility for food supply (MW1). Some respondents from Makueni recognised that factors such as consecutive failures in the maize harvest may push farmers onto an 'alternatives to maize' pathway (MW1), but others suggested that they were unlikely to be pushed away from maize because it is their most fundamental means of food security, and so would only be viable if, for example, they could depend on affordable and reliable access to maize through markets.

Contrary to this common perspective, however, over the past six years, Benson Nzilani (M16) has reduced the area that he designates to maize growing from four acres down to just half an acre, which is now purely for subsistence. He explains that repeated incidence of drought and reduced soil productivity, combined with the rising cost of inputs, was making maize farming unprofitable. Two separate schemes run by extension workers from the Ministry of Agriculture (MoA), had encouraged the growing of non-cereal market crops in his local area in the Makueni District. The first, in the 1990s, promoted sisal planting (involving extension services provided through the Kenya Sisal Board and MoA), which Benson's father chose to invest a small amount in (dedicating approximately ¼ of an acre) with some economic success and the sisal growing area of the farm expanded to approximately 1 acre over the late 1990s and early 2000s, but he does not feel that there is a strong enough market to be able to depend on sisal growing for income. More recently, and on the advice of agricultural extension officers, he has invested in orange fruit trees, which are irrigated by hand with water from a nearby borehole during the dry season. He began with 5 trees in 2005 and now has a three acre plantation and a regular market in Wote town. He also maintains a small patch of kale within the compound for home consumption. Benson felt that his farm has benefitted from following the advice of agricultural extension workers, although he recognises that other farmers, whose fruit trees have succumbed to disease, have felt let down by the advice they received.

Judith (M12) is one such farmer; in 2008 she replaced a half acre plot of maize with passion fruit seedlings based on the advice of non-governmental agricultural extension workers that were promoting cash crop farming in the Kathonzweni area. The trees produced a good harvest in 2011, but in 2012 they were struck by a soil-borne disease that affected the entire crop and she was left with no choice but to clear the whole plantation. She felt that she was not made aware of the risks of planting passion fruit and believes that it was an ill-advised investment. She is planning to revert the area back to intercropped maize and beans, which she feels she has more experience of and a better understanding of how to grow well.

It is not only in growing alternatives to maize, that farmers experience ignorance, however. In 2012, several farms suffered from an epidemic 'lethal maize necrosis' disease, which hit large parts of the country (Wangai et al., 2012). Although there was a national level response and farmers in the worst affected areas of the country (it was particularly concentrated in the Southern Rift Valley) were supported through the Ministry of Agriculture to access potato, or other, seeds to plant in cleared fields for an interim season in order to ensure removal of the virus from roots in the soil, several farmers in Makueni felt that they had not received advice or support on how to respond to the disease (M2, M5, MW1), and were left not knowing how to respond to the disease. A number of participants told stories of how farmers, without knowing to do otherwise, simply cleared roots from the soil and planted next season's maize as normal, with a significant risk that the disease would reappear.

As with other technologies, a lack of information is as a major constraint on the ability of participants to envisage the adoption of GM maize as a narrative of change. In both districts, participants were largely unaware of what a GMO is, had heard very little about on-going maize breeding research and development in Nairobi, and knew only of some success claims (e.g. GM maize will double yields) and some scare stories (e.g. GM maize causes cancers), without any background knowledge with which to interpret them. Some were even unsure if conventionally bred maize could act as a comparison, questioning whether GM would require that land preparation, planting, harvesting would be done in the same way (NW3). Health impacts were universally identified as the most important perceived risk in adopting GM maize across the workshops. But there was also recognition that this was based on incomplete information received through the media and word of mouth communication (NW2, MW2) and an older man at the second Nandi/Nyando workshop pointed out that this information is very difficult to interpret critically (NW3). Narratives of conspiracy and distrust also play a role in attitudes towards GMOs. Beliefs that Kenyans are unknowingly consuming GMOs, which was separately mentioned by two participants from the second and third Nandi/Nyando workshops, were apparently linked to a distrust of, or a sense of ineffectiveness of, regulating institutions. Similarly notions that GMOs were being introduced in to Africa by the United States in order to control population growth (again mentioned by more than one participant) have apparently been built around rumours of conspiracy associated with US international agendas of control and a distrust of the Kenyan Government's concern with the social protection of its citizens (NW2). A young man at the third Nandi/Nyando workshop, along with others, argued that these rumours were untrue 'media scare stories' (NW3), but discerning these stories from useful information on which to make judgements about the technology is difficult in a context where information is received in a piecemeal way and largely through journalistic media.

Ignorance is sustained, if not exacerbated, within smallholder farming as a result of knowledge exchange barriers that come in the form of reductions in agricultural extension and information provision and a lack of opportunities to access information about new research and technologies (i.e. structural barriers), as well as distrust of external actors and interventions, based on experiences of negative interactions. In response to such barriers, many farmers are forced to depend on their own internalised knowledge, experiments, indicators, and value-judgements. The following section describes some of the points at which values and choices enter into an ambiguous process of farm management and change.

The Ambiguities of Decision Making on Smallholdings

Across participants' stories of, and perspectives on, agricultural change there are not only multiple sources of uncertainty and ignorance, but a variety of choices and strategies in response. Different farmers choose to seek out information on climatic changes or new technologies and varieties in different places, interpret this information on the basis of different judgements about reliability or preferences for different indicators and in relation to different adaptation priorities, and make different conclusions in response to these interpretations. This diversity reflects the ambiguous nature of knowledge about smallholder maize farming.

The varietal trait selection exercise described earlier in the chapter was one of a number of examples in which different value judgements, relating in this case to judgements about the relative merits and desirability of different maize traits, emerged. Very different perspectives on the desirability of the expression of drought tolerance in maize came out of the Nandi/Nyando workshops. Low-priority perspectives were rationalised on the basis of the rarity of low rainfall events during the growing season in that region and high-priority perspectives rationalised on the basis of a preference for growing a second crop in the short-rain season. Neither perspective is obviously less rational than the other, yet they result in opposing conclusions about priority traits.

Some examples of ambiguity that were observed in reference to decisions about the three main categories of change in smallholder maize farming in this research are listed in table 7.

Table 7 Examples of ambiguity within smallholder farming decision-making

	Ambiguities
Changing Land Management and Preparation	• Different choices of indicators of weather and climatic change • Different judgements about optimal levels of fertiliser input • Different judgements about the reliability of different sources of information • Different decisions about number of seasons to trial conservation agriculture over • Different interpretation of the results of trials of conservation agriculture
Adopting New Varieties and Technologies	• Different judgements about the reliability of different sources of information • Different preferences for maize varietal traits • Different evaluations of the performance of post-harvest storage techniques
Alternatives to Maize for Market and Home Consumption	• Different judgements about the reliability of different sources of information • Different assessments of the market opportunities for cash crops • Different preferences for the taste of non-maize cereals • Different levels of confidence in ability to adjust to growing non-maize crops

One of the most notable sources of ambiguity across almost all decision-making in smallholder farming, comes from the farmers' need to make judgements about the reliability of various sources of information.These judgements are made in all cases whether it is information about new techniques and technologies, projections of climatic change, or market opportunities, and whether it comes from relatives and close neighbours, agricultural extension workers, salespeople, the media, or external projects and programmes. The following section of this chapter looks more closely at the ways that interactions with others shape these judgements. Whilst there is evidence of positive interactions of learning and knowledge exchange, both within communities and through external projects, this research particularly revealed ways in which distrust and scepticism have been built as a result of negative experiences of interaction with, and the misleading communication of incomplete knowledge from, external actors.

Interaction with External Actors and NGOs

One of the key brokers of knowledge and resource exchange for smallholder farmers are non-governmental organisations (NGOs), and there were a number of examples in the research locations of beneficial interactions between farmers and NGOs. John Kibete and his wife (N5) have a number of small income-generating projects, they run a local convenience store, rear chickens, and have a small vegetable plot (the products of which they both sell and consume). They explained that the economic challenge of maize farming, as well as John's age (62), are the reasons that he no longer rents the five acre plot on which he used to do maize farming 10 years ago, but instead tends just one acre. After the 2011 harvest John joined the 'One Acre Fund' initiative established in the area by an American NGO. It is a microfinance initiative that is designed to help smallholder farmers get access to affordable and timely fertilisers, certified seeds, and top dressing. John pays a total of 9,000 KES into the fund over the course of the year, and once he has contributed half of this money (4,500 KES) he is supplied with 10kg of hybrid seed, 100kg DAP fertiliser, and 50kg of CAN top dressing (the total market price of which would be 12,200 KES (if unsubsidised fertiliser)). In addition all members of the One Acre Fund commit to working for a day on five of the other members farms during land preparation and harvesting. The remaining 4,500 KES (and the beginnings of next year's payment) can be made once John has sold 15 bags of maize back to the Cereals Board (for a total of approximately 40,000 KES) and his 15 year old son's school fees have been paid. The scheme involves two types of interaction for John, firstly with external project officers who manage the fund and supply inputs, and secondly with fellow farmers whose cooperation improves the purchasing power of the group and whose collective labour facilitates efficient land preparation and harvesting. Simultaneously it reduces interaction between the farmer and the input supply systems, actors in which John has little trust, having experienced difficulties in obtaining subsidised fertiliser and believing that he has previously been sold 'fake' seed.

In Nandi/Nyando a number of farmers pointed out that organisations such as the One Acre Fund and charitable agriculture training centres, such as that located in Kipkaren which was providing training for local farmers on a range of techniques and technologies, have replaced government-provided agricultural extension workers as the main source of external information and advice for smallholder farmers. John recalled that 'we used to have someone from the Ministry of Agriculture who would visit the farm; he helped people to build irrigation systems.... [and he would] tell us about the best seeds... I think he stopped coming maybe fifteen years ago, a long time'. Whilst John felt that he was still able to get a lot of advice through agrovets and organisations such as the 'One Acre Fund' and a local NGO-run agricultural training centre, other farmers expressed concern that they had needs that were no longer being met since agricultural extension workers became absent from the area in the 1990s (N19).

Francis (N26) believes that farms in the area desperately need soil testing; this was something that was provided back in the 1980s through government extension workers but has not been done since and many farmers have long since stopped following advice that was given at the time about applying lime to the fields to neutralise the acidification effect of using DAP fertiliser. Francis explains that he is following the generic advice of his local agrovet and applying 2 bags of DAP per acre, but he wishes that he could have his soils tested so that he could be better informed about the most effective inputs for his soils.

In both districts there has been an apparent reduction in the amount of engagement that smallholder farmers have with governmental agricultural extension workers, consistent with the decentralization and reduced expenditure on public sector agricultural extension that formed part of the structural adjustments of the 1980s. A number of respondents felt that extension services are now more focused on larger-scale farming (N8, N19). But there is also evidence that the gaps in government supplied extension are being filled by non-government organisations, such as the One Acre Fund, with some apparent success. Whilst this extension work clearly plays an important role in informing farmers about new opportunities and supporting them to take advantage of them (as in the case of sisal planting, or obtaining access to inputs), the provision of inaccurate or incomplete information, especially where this incompleteness is not explicitly communicated, can exacerbate the risks associated with change and a closing down of opportunities for change. In Judith's case described above, for example, her experience of passion fruit disease and feeling of being misinformed about the risks of planting them led to a subsequent distrust of information and pushed Judith back to planting maize and beans.

There is a clear difference between the generic advice of an agrovet or the Kenya Seed Company about how much fertiliser to apply per acre, based on broad agro-ecological zoning and outdated soil maps, and the field specific testing of soils, explanations of mineral and pH requirements, and tailored inputs, that agricultural extension work offered. Whereas the former represents a unidirectional communication of a single accepted wisdom, the latter involves farmers in the process of scientific experimentation and observing and understanding findings.

Unlike interactions with agrovets or at one-day agricultural shows, which for many smallholders represents the main source of information about agricultural techniques and technologies, organisations such as the Kipkaren agricultural training centre can achieve a more sustained engagement with farmers. In the case of training in conservation agriculture, for example, farmers attended demonstrations and (although the centre is somewhat guilty of promoting the

God's Way farming method as a guaranteed technical fix) they were encouraged to conduct their own on farm evaluations and received support and follow-ups through the training centre for establishing and monitoring these trials. In David's case, for example, although God's Way farming has not worked for him in the way that was suggested it might he feels that he has learnt about the principles and the uncertainties of conservation agriculture techniques and appreciates the support of the agricultural training centre in these trials.

Deliberative forums such as the participatory scenarios workshops conducted as part of this research facilitate the negotiation of knowledges; involve stakeholders, both within and across barriers, in the provision, analysis and interpretation of knowledge; and allows these knowledges to be reinforced and transformed through social learning. Evidence that this began to happen within the workshops came from participants asking questions about 'the completeness of information' and 'the assumptions on which it is based'. Instead of simply asking *'are GMOs safe to consume?'* participants asked about the number of years over which GMOs had been consumed in different countries and the incidence of related health impacts, indicating an internalisation of the processing and analysis of information.

In response to incomplete knowledge about the operation of climates and markets, it is important that farmers do not become tied to relationships of dependence on actors and unidirectional communications of information that are not acknowledging of the uncertainties, ambiguities, and ignorance within it. Significant risk for the farmer is created, for example, as a result of unavoidable reliance on input supply systems that often fail them because of corruption (as in the case of fake seed) or supply chain failures (as in the case of government subsidised fertilisers), and is exacerbated by a lack of opportunities to participate in generation and negotiation of knowledge (as was offered through more frequent interactions with extension workers for example).

Conclusion

The stories of farmers from the two districts provide insight into interactions with different types of interventions and reveal a diverse set of strategies that farmers have employed in order to manage risks or take advantage of new opportunities. These strategies rarely rely solely on external actors or information (such as weather forecasts or the prescribed practices of agricultural extension workers) often because farmers feel that they have failed them in the past or because they are simply not there; rather they utilise local and creative systems of knowledge production that drawn on multiple evidences and experiences. The Humanitarian Futures climate workshop described in the previous chapter spoke of the highly prescriptive nature of many interventions that target the adaptation of smallholder farmers to environmental uncertainty and change. But the subsequent stories of smallholder farmers in Nandi/Nyando and Makueni reveal a history that has taught farmers to be cautious about such prescriptions and interventions, because they often carry risks of their own. The chapter has revealed a knowledge culture that is, in many ways, similar to that of climate-crop modelling in that it is based on experimentation and verified through real-world observation. However, farmer decision-making is not easily modelled; assumptions about rational decision-making inevitably fail to take account of the way that social interactions and institutional failures shape a multi-faceted and complex decision-making process.

Agricultural change may see farmers having to engage with new markets and actors. As such they necessarily introduce new uncertainties, not defined by climates, but by social relations. The adoption of GM varieties is a prime example because it is likely to bring farmers into contact with new sets of regulations and new 'traceable' chains of seed supply and post-harvest processing, systems in which there is already little trust (as in the case of the supply of fake seed). Contextualised histories shape complex relationships between smallholder farming and agricultural development projects and regulations with important implications for the uptake of technologies and regulatory compliance. Chapter Nine looks more closely at these interrelationships and discusses how farmers may play a greater role in shaping technology development and how development projects address issues of distrust and improved information sharing.

The reality is that farmers regularly utilise information, techniques and technologies that are offered, but on their own terms and within their own systems of knowledge production and decision-making. They evaluate its validity, reliability, and trustworthiness against their own experiences and experiments. However, whilst participants identified their own agency to analyse and act on information, they also identified limitations in their agency to access and obtain information. A lack of transparency about the assumptions and uncertainties inherent within information inevitably increases the risk associated with acting on it, and it is clear that farmers commonly felt that they did not have enough of an understanding of the completeness of knowledge on which information was based in order to critically analyse the piecemeal information that they received. The credibility of different information providers is linked, at least in part, to their visibility and level of engagement with farmers, their willingness to involve farmers in the generation and interpretation of knowledge, and the transparency with which they communicate the incomplete nature of knowledge.

It is within this context of smallholder farming that the DTMA and WEMA initiatives seek to bring about adaptation, modernisation and change. The findings of this chapter suggest that assumptions about the demand for, and adoption of, the DTMA and WEMA technologies, may be less straightforward or rational than is suggested in the narratives advanced by the projects. The following chapter considers these projects, and their origins, contestation, and implications in more detail; points of connection and disconnection between the DTMA/WEMA narrative and the nuanced realities of smallholder farming will be returned to in the discussion chapter.

Chapter Seven: The WEMA and DTMA Initiatives

Crop Breeding for Impact-at-Scale and an Uncertain Future

In this third empirical chapter, focus turns to the DTMA and WEMA projects which are aimed at improving the resilience of vulnerable smallholder farmers to the uncertainties of climatic change by developing and disseminating drought-tolerant maize varieties. In this chapter, an analysis of the context concentrates on the histories, cultures and priorities of the funders and institutions within which the DTMA and WEMA projects operate. It is argued that it is within the increasing entry into public-private partnerships of the CGIAR; the resource limitations of KARI; the history and trajectory of research and development in crop breeding; the 'impact at scale' targets of philanthropic donors; and the commercial interests, business culture and charitable participation of private partners that the project narratives fit, comfortably at points but not so at others. The chapter particularly focuses on the ways in which the institutional arrangement of the projects dictates certain approaches to technology development, styles of science, and values, as well as shaping assumptions that are made in response to incomplete knowledge about future change (in climates, farmers' strategies, and national regulation). The chapter reveals points of conflict between the WEMA/DTMA narrative and those revealed in the other empirical chapters and highlights where these relate to assumptions that fit with and support the DTMA/WEMA narrative rather than learning-based engagement with other actors.

Three particular areas of operation are discussed as examples of institutionalised activity: crop genetic modification; crop trials; and social impact assessments and, as in the previous chapters, the incomplete nature of knowledge that is produced within, and presented from, this context is deconstructed and described in terms of its uncertainty, ignorance and ambiguity. The nature and extent of interactions between the projects and other stakeholders, such as smallholder farmers and technology regulators, is described in the later part of the chapter.

The Institutional Context of WEMA and DTMA

Every morning Kenyan groundskeepers in standardised green overcoats sweep away leaves from the perfectly paved driveway, wash the terracotta-tiled walkways, and attempt to scare encroaching monkeys away from the grounds. Their task is to maintain the manicured idyll of the World Agroforestry Centre, a picture of modernity that sits within Nairobi's Karura Forest. The leaves on the road and the monkeys on the roof are constant reminders of the natural and political ecology within which this wealthy CGIAR institution is located. Karura forest's own history is as political as the organisations that it now plays home to. As a site of local resistance to powerful change, Karura has been both a place of occupation for rebel militias during the Mau-Mau uprising against the British colonial army, and, more recently, was the location for one of the country's most famous anti-capitalist conservation protests, led by the environmental campaigner and champion of community-led conservation, Wangari Maathai.

The World Agroforestry Centre (known by the acronym ICRAF) is one of two CGIAR campuses in Nairobi and it hosts a range of CGIAR organisations, shown in the overwhelming display of acronyms and logos on the impressive billboard at the campus entrance: CIMMYT (The International Maize and Wheat Improvement Centre); ASB (Alternatives to Slash and Burn); ICRISAT (International Crop research Institute for the Semi-Arid Tropics); IITA (International Institute for Tropical Agriculture); CABI (Centre for Agriculture and Biosciences International), and more. There are more still across town at the International Livestock Research Institute (ILRI), the CGIAR's other Nairobi campus, which hosts the AATF (African Agricultural Technology Foundation); BeCA (Biosciences Eastern and Central Africa); and ISAAA (International Service for the Acquisition of Agri-Biotech Applications), amongst others. The endless acronyms of projects and partners, as well as a vocabulary of institutionalised terms ('scale-neutrality', 'climate-smart agriculture', 'appropriate technology', 'resilience') represent the language of the CGIAR; acting as a linguistic uniform for those in the group and inevitably excluding those that are unable to decipher the code.

The headquarters of Kenya Agricultural Research Institute (KARI) is just a mile away from the ILRI campus, but is culturally and environmentally distinct from its international counterpart. The headquarters has the 1980s signature of a Kenyan government building. Its faux-wood clad conference rooms display the standard-issue portrait of the president; the colours of the Kenyan flag are in the furnishings and the flag itself is on display at every turn; and countless plaques commemorate visits from international ambassadors and politicians. The slightly decrepit buildings subtly hint at resource limitations within the institute and KARI's workshop advertisements and technical poster displays are simple in appearance, lacking the stylised branding of ICRAF and ILRI outputs.

CIMMYT's presence within the ICRAF campus is relatively innocuous, housed within a single story office block that has the feeling of a temporary addition at the back of, and disconnected from, the main ICRAF building. The principal crop breeder on CIMMYT's DTMA and WEMA projects in Kenya, works from an office that looks as though it is struggling to contain the countless stacks of folders and papers that are piled at the base of its jam-packed, ceiling-height shelves and contains records and reports that detail CIMMYT activity going back decades. 'Before climate change was even being talked about, CIMMYT was trying to address drought through genetic advances' (DW1), he explains with a subtle pride and obvious passion for his work. In recounting the history of the Africa Maize Stress Project, he offers a detailed description of the breakthrough discovery about phenological variability in the sensitivity of maize to water stress (i.e. that it is most sensitive during flowering) and explains how this has informed a new method of crop breeding under controlled-stress conditions.

It is in the collaborative environment of the maize field that the contrast between the wealth of the CGIAR and the older and more nationalistic identity of KARI becomes indistinguishable across a workforce that is universally passionate about crop breeding. KARI and CIMMYT's crop breeding stations are hives of activity and product, endless lines of maize are planted and labelled with long numerical codes on blue tags hung around the stalks, and men and women in white lab coats busily take measurements of the maize stalks, harvest cobs, pollinate the silks of young maize plants and wrap polythene around the new tassels. Seasons do not count for much in these controlled environments. Extensive irrigation systems create green, oasis-like fields in which there are maize plants at all stages of their lifecycle and in contrast to sandy surroundings of the semi-arid landscape.

The WEMA field trial site is located at the end of a long dirt track that seemingly takes you far away from the rest of the Kiboko maize plantations. The sign at the entrance to the site, which details the organisations involved in the trial, the ditch and high wire fence that surround the perimeter, and the armed security and disinfectant bath at the gate, set this apart from any of the other maize trials taking place at the station. Visitors to the site must provide details of their visit in the log book and be accompanied by a senior member of the project staff. The trial site is void of the busyness of the rest of the research station and has a quiet order about it. The seclusion and quietness of the site, its added security and perfect order, subtly set this, otherwise unspectacular, maize apart as transgenic. This small stand of maize is the product of years of technological development and policy debate alike, and is a symbol of the modernisation of agriculture that teams of investors and scientists have endeavoured to realise.

Within Nairobi's CGIAR campuses, KARI research stations and universities there is a whole generation of crop breeding experts, described by one respondent as Nairobi's 'community of scientists' (DW20), predominantly comprised of men in their 40s and 50s, all well-known colleagues or former colleagues of one another, who invariably began their academic careers in agricultural science at the University of Nairobi and went on to obtain plant breeding and genetics doctorates from Cornell, or similar prestigious universities in the United States and Europe. These experts, who now occupy high-paid positions, have successfully leveraged significant investment in biotechnology infrastructure and research and development projects, and are succeeding in making Kenya, as the same respondent described it, one of Africa's 'leader[s] in agricultural biotechnology research and development' (DW20). Another respondent described the status of agricultural biotechnology in Kenya by saying: 'you know, the sun rises in Kenya, you can expect that good things will come from this place' (DW8).

The quiet order of the WEMA trial site is reflective of the operations and approach of some of the corporate actors that have contributed towards the endeavour of crop breeding development in Kenya. Monsanto's Nairobi offices are smart and clinical, its open-plan minimalist interior, white walls, flat screen information boards and glass fronted office pods are a stark contrast to the paper-filled offices of CIMMYT and the 1980s-style of the KARI headquarters. The differences between Monsanto's corporate style and the more research-oriented operations of CGIAR centres and KARI make for a working relationship that has required adjustment. As a respondent from Monsanto explained:

> 'It has been a learning process, but it has been very successful... there are different styles of work and different speeds, efficiencies... it requires a lot of communication and organisation' (DW11)

These are the settings of the DTMA and WEMA crop breeding initiatives. Each location, and the people and organisations that work within them, represents a historical context, a set of priorities, methods, and institutionalised ideas about the future of African agriculture. As revealed in this chapter, these settings shape approaches to interpreting the uncertainty of real world and changing environments within crop trials, the maintenance of ignorance about the socio-economic impacts of the technology, and contested and ambiguous perspectives on the value of different breeding strategies. In the bringing together of these diverse contexts and actors into one set of projects, and in the construction of a unified and unifying narrative, there is an inevitable and political process of negotiation.

The DTMA/WEMA Narrative

The story of agricultural change advanced within the official communications and reports of the WEMA and DTMA is of a 'pro-poor' technological solution to problems of poverty and food insecurity that are largely ecologically and climatically driven. Such a narrative is evident in the following statements, which are taken directly from a WEMA policy brief:

> 'Persistent incidences of drought in Kenya have continued to threaten the food security situation and subjected millions of Kenyans to starvation… Modern biotechnology provides a major opportunity to address perpetual maize shortages that are now being compounded by new threats triggered by climate change… WEMA was launched as a demand driven technological innovation designed to strengthen the resilience and adaptive capacity of maize farmers to cope with drought… Stable and reliable yields will revitalize and build the confidence of farmers in maize production. Stability in yields will give farmers the confidence to invest in other productivity enhancing technologies such as sustainable soil management practices… It is projected that maize varieties to be developed could increase yields by 25 percent compared to current varieties. This increase would translate into about two million additional tonnes of food during drought years... Policy makers within the relevant government institutions and agencies should create an enabling environment and make science-based decisions that will facilitate the conduct of confined field trials and other biosafety regulatory steps that will eventually lead to commercialisation of WEMA seed varieties'
> ('Reducing maize insecurity in Kenya: the WEMA project'; Water Efficient Maize for Africa Project (WEMA) Policy Brief, November 2010)

Whilst there are important distinctions between DTMA and WEMA in terms of their mandate and approach – DTMA can be broadly described as a collection of research initiatives aimed at improving the resilience of maize farming to drought and whereas WEMA is a more product-focused project – they both ultimately advance a very similar narrative. Implicit within their technology-driven framing of problem and solution are a number of key discourses that have been commonly identified within a growing literature on technology-driven policy interventions (Glover, 2009, Hisano, 2005, Jansen and Gupta, 2009, Brooks et al., 2009), inclusive of ideas about the 'pro-poor' nature of technology and the linking of small scale activity to grand and urgent narratives of global change.

There are similar pressures within both DTMA and WEMA to deliver successful outputs, not least to sustain funding streams, which in both cases, have three to five year shelf lives. Representatives from CIMMYT and AATF expressed similar sentiments about the need to begin looking to the next phase of the project as soon as the current one begins (DW1, DW8, DW9). Whilst there is less reliance within DTMA on its deliverables being end-technologies, in part because it has a steady and growing portfolio of successful varieties developed in most of its operating countries, in both initiatives there is an institutional set up that is, to different extents, structured around the ultimate delivery of technology. This motivation is closely linked to two sets of interconnected discourses that are particularly evident in the case of WEMA, but are similarly identifiable within DTMA, and are influential in shaping the actual operations of the initiatives.

The first relates to the idea of a 'one size fits all' technological solution. Common to both WEMA and DTMA are explanations of the 'pro-poor' nature of technology, which are often based on assumptions about its scale-neutrality; that it can be adopted with equal efficiency and yield gains within a one-acre plot as a thousand acre plot, and so the commercialisation of the seed will not unfairly advantage the wealthy large scale farmer:

> 'One of the greatest attributes of biotechnology is its scale-neutral applicability. The power of the technology is delivered through a seed that can be grown by any farmer, regardless of their operations and farm size, without additional equipment or large capital investment.' (AATF concept note 'Combining Breeding and Biotechnology to Develop Water Efficient Maize for Africa (WEMA)'; p.3[63])

There has been some critical engagement with this idea within DTMA, which has incorporated social studies of technology adoption and impact amongst smallholder farmers (e.g. DTMA's 'Characterisation of Maize Producing Households' studies), but it has remained relatively peripheral to the dominant narrative of technological solution. By building resilience into the seed, the narrative suggests, it offers resilience to all. The Asian green revolution is the regularly referred to blueprint for such an intervention[64]. The impacts of the project, as with the green revolution, are often elaborately described in aggregated terms – total production gains, a generalised category of smallholder 'maize farmers', and impact across sub-Saharan Africa.

The second set of narratives is evident in the use of business language such as 'demand-driven' and 'facilitating commercialisation'. This is more specific to the WEMA project, which, perhaps because of the organisations involved and the more product-centred nature of its mandate, has a particular business-mindedness that is not evident within DTMA. The technology developed within WEMA is often presented as an economically rational and efficient intervention, and the WEMA business model is centred on achieving ambitious targets through 'streamlined supply chains' (DW9) within regulatory environments that allow for rapid spill-over of the product across national boundaries.

[63] http://www.aatf-africa.org/userfiles/Wema-Concept-Note.pdf
[64] E.g. see WEMA Concept Note (http://www.aatf-africa.org/userfiles/Wema-Concept-Note.pdf) references to 'enabl[ing] a Green Revolution and economic development in Africa' (p.1)

The following section looks at the assumptions, values and evidences that underpin the broad narrative of change that the DTMA and WEMA projects both advance and operate within, and reveals the way in which styles of science and approaches to incomplete knowledge are both shaped by and act to legitimise the priorities and motivations that are reflected in this narrative.

The Science and Incomplete Knowledge of DTMA and WEMA

The flow diagram presented in Chapter Four (Figure 7) illustrates a multi-stage and multi-sited process of technology development and dissemination that takes place within the WEMA project. This provides the basis for the following analysis of the nature of knowledge within the DTMA and WEMA projects and it makes particular reference to three aspects of this process, which involve different combinations of actors in each project:

- Crop genetic modification, which involves germplasm development within central CIMMYT breeding stations and, in the case of WEMA, includes the importation of material from Monsanto's US laboratories and state-of-the-art breeding programmes through the KARI Biotechnology Centre and BeCA facilities.
- Crop trials, which in the case of DTMA take place in a combination of centralised stations, such as the Kiboko research station (managed by CIMMYT and ICRISAT), decentralised (regional) KARI research stations, and on on-farm field stations (managed by KARI and seed suppliers) across the country; and in the case of WEMA is limited to a confined field trial site within the Kiboko station, which is managed by CIMMYT and whose regulation is overseen by KEPHIS reporting to the NBA.
- Socio-economic impact assessments, which in the cases of DTMA and WEMA (as well as IRMA) have largely been conducted by socio-economists at CIMMYT, in conjunction with the AATF, but DTMA and WEMA reports about impact also draw on studies from the University of Nairobi, KARI, and ISAAA about related crop developments and perceptions of GM crops.

Within these components of the DTMA and WEMA projects, there is evidence of assumptions, choices, and value judgements that are made in response to uncertainties, ambiguities and ignorance. As is argued later in the chapter, the incomplete knowledge that is generated within these components of the projects represents the basis of the narrative described above and is often communicated in such a way as to legitimise it. The following analysis deconstructs knowledge claims associated with DTMA and WEMA breeding, crop trialling and socio-economic impact assessments.

Uncertainty in Crop Trialling

The Africa Maize Stress (AMS) project, jointly implemented by CIMMYT and IITA in 1998, represented a methodological turn in CIMMYT's efforts to breed for drought tolerance. Rather than targeting early maturity – i.e. crops with the ability to escape drought during a short rain season – the AMS project attempted to trial, select, and monitor the performance of genetic lines when grown under water-limited conditions. AMS pioneered a system of participatory varietal selection for drought tolerant lines, described in the type-writer-font text of a stapled A4 participatory breeding handbook, which sits among a shelf of somewhat glossier and more modern iterations of, essentially the same (minus some of the outdated language of 'lay' knowledge), guidelines to 'stakeholder participation'. This shelf, equally jam-packed, is in the office at the other end of the CIMMYT corridor, that of CIMMYT's Nairobi-based socio-economist. He explains the concept of the 'mother-baby' trial methodology, in which farmers themselves are given the opportunity to identify preferred varieties from a larger trial site (the mother site) using evaluation scoring sheets, and then evaluate those selected varieties on small on-farm trials (the baby site), in which they have the opportunity to compare the new varieties to those which they commonly grow, under common land management conditions and constraints (Bänzinger and Diallo, 2004).

> 'Participatory selection reveals farmer preferences and helps to identify the best varieties for an area… if a farmer has been given the chance to evaluate a variety they are better informed and can inform others… it improves the appropriateness of the technology and adoption.' (DW7)

AMS represented a concerted effort to reorient the technology development focus of CIMMYT towards a more locally appropriate and stakeholder-inclusive project and through partnership with the Kenya Agricultural Research Institute (KARI) it was able to incorporate participation into a previously exclusive crop breeding programme (DW3).

As controlled simulations of farm conditions, crop trials provide information that, whilst representing a useful indicator of varietal performance under generalised agro-climatic conditions, is nevertheless incomplete with regards to the specific thresholds and combinations of conditions that vary from farm to farm. Uncertainty about how crops will perform in the 'real world' inevitably comes as a consequence of spatial variability in soil properties and microclimates as well as differences in land management and planting practices. The extent to which this complexity can be captured within a crop trial is limited and there is a trade-off to be made between the size of area covered by crop trials and the extent to which local conditions can be accurately simulated.

An injection of funding from the BMGF facilitated a dramatic up-scaling of the AMS project as it became DTMA. Whilst CIMMYT has continued to struggle with ironing out the challenges of the mother-baby approach, increasing emphasis has been placed on streamlining the breeding programme and achieving impact-at-scale. There has been a parallel process of scaling up of the breeding strategy which attempts to reconcile the need for varieties that are tailored to agro-ecological conditions, with this expanded continent wide focus to its operations.

CIMMYT's preliminary germplasm selection and breeding activities are targeted at 'mega-environments', which are crop specific and delineated on the basis of climates, soils and biotic and abiotic stresses to create aggregated zones of similar ecologies, such that a large pool of genetic material can be narrowed down to appropriate varieties from which to breed for that environment (i.e. they target the primary stresses associated with a mega-environment).

> 'The CIMMYT and IITA breeding programs are organized around the concept of 'mega environments', i.e. areas with broadly similar environmental characteristics with respect to maize production (Setimela et al. 2005). Similar combinations of climatic and edaphic conditions exist within and across continents, allowing identification of maize mega-environments on the basis of GIS data. As climatic conditions change at particular sites, it will be possible to reassess the mega-environment assignment of the site, guiding breeders to develop appropriate new germplasm for future climates.' (The CGIAR Maize RP Outline, p. 58[65])

Across sub Saharan Africa, CIMMYT identifies six maize mega-environments or agro-ecological zones[66], all of which are present within Kenya, a country that shows particular agro-ecological diversity as a result of terrain differences and both ocean and lake effect rainfall systems. In partnership with national agricultural research centres (e.g. KARI) germplasm that has been developed at centralised sites (such as the CIMMYT-ICRISAT-KARI station at Kiboko) is selected and trialled for specific agro-ecological zones at KARI stations within these zones. These national research stations are, effectively, the equivalent of baby trials, and the responsibility for coordinating on-farm trialling, which usually employs the same mid-large scale farms each time (DW12), is delegated down to KARI, which, as a KARI representative explained, has limited resources and capacity to implement these trials (DW12).

[65] Available at: http://maize.org/our-strategy/crp-maize-proposal (accessed on 5/2/13)

[66] Dry lowland; Dry mid-altitude; Highland; Wet lowland; Wet lower mid-altitude; Wet upper mid-altitude

A discussion of the comparison of AMS with current CIMMYT breeding with a CIMMYT social scientist suggested that crop breeding has become targeted at much more aggregated environments than was possible during AMS (DW7) and there is little space for social and economic geographies, both within and beyond the boundaries of these zones to be reflected in the results of crop trialling (geographies that might otherwise be reflected in a more locally targeted and participatory breeding process). The result of the scaling up in crop breeding and trailing that took place between the AMS project and DTMA and WEMA projects is that there has been an inevitable loss of farmer engagement with the breeding process, which happens on on-farms trials too far down the line to really influence the breeding strategy.

Essentially there is a trade-off between the practicalities of targeting varieties for large-scale impact and responding to the local conditions and requirements of farms. Even within a system whereby breeding is scaled down and gradually decentralised from more generic trial sites performance based selections of germplasm take place at early stages under generic conditions, and the assumptions that underpin these selections act to frame breeding outputs.

The trialling of transgenic varieties is even more limited due to the biosafety requirements at trial sites. WEMA currently has permission for just one trial site within Kenya, at the Kiboko research station. Here, a reliable absence of rainfall during the dry season allows for watering of the crops to be carefully controlled and the performance of varieties under water stress to be evaluated. However, the limitations of trialling within just one location mean that agro-ecological conditions for the trial cannot be varied and a fairly arbitrary decision has to be made about the generic conditions under which trialling happens.

There are two plots of maize lines set up within the trial site compound, one which is well watered through irrigation lines and another which is water-stressed (this plot is irrigated up to a point but has water removed 45 days after planting). On both plots, lines alternate between transgenic and non-transgenic lines (although they are not labelled as such). A total of 13 transgenic lines are being trialled on each plot, and at harvest time, careful records are kept for each row of the days between male and female flowering; senescence of leaves; number of cobs per plant; and yield (weight of shelled grain).

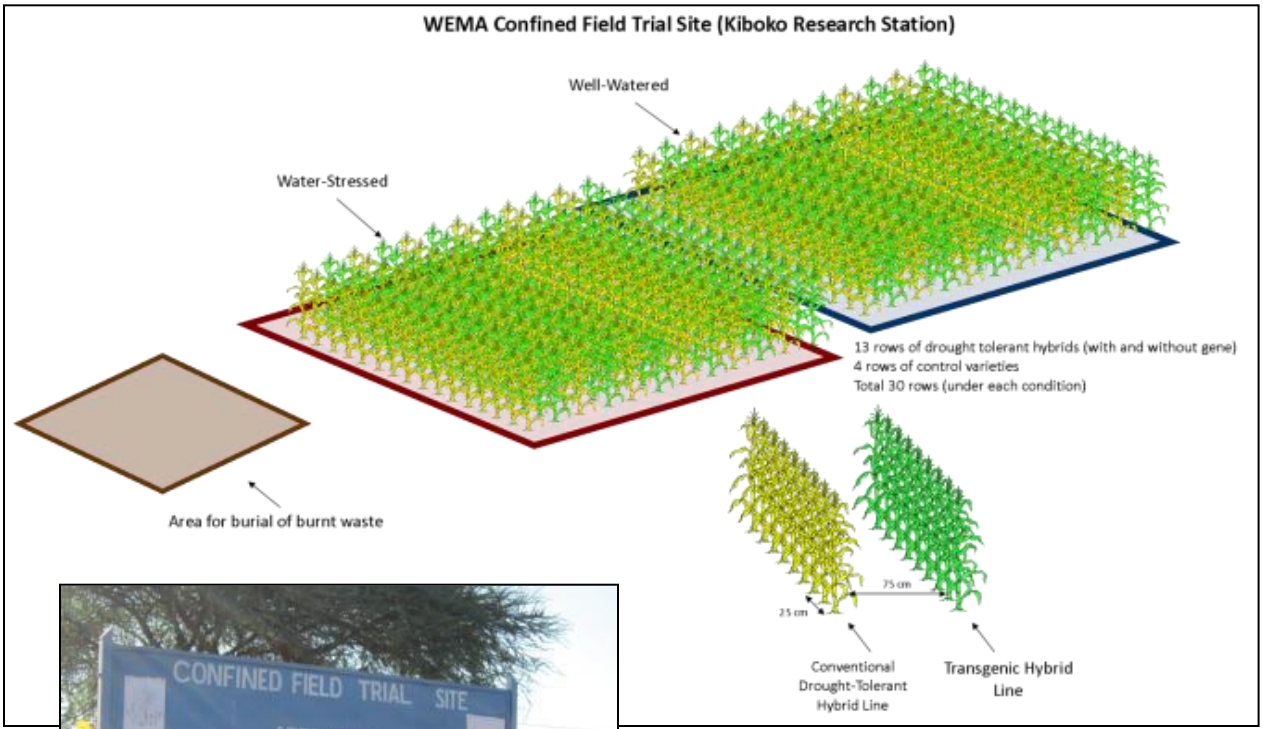


Figure 15 Diagrammatic representation of the WEMA trial site and a photograph of the sign at the entrance to the site (source: author)

Although the design and set up of the field trials have to be approved by the National Biosafety Authority (NBA) and closely monitored by the Kenya Plant and Health Inspectorate Service (KEPHIS), and there are clear guidelines about ensuring 'confinement'[67], designing and evaluating study itself involves a number of methodological choices, to be made by the crop breeders, which inevitably impact on the evidence produced (Table 8).

[67] Requirements include maintaining a 200m separation distance between the trial site and any non-transgenic maize, ensuring that anyone entering or leaving the site disinfects the soles of their shoes and tires, and fully clearing all stalks and roots and burning all of the material (within the trial site compound) at the end of each harvest period.

Table 8 Methodological choices in the design of the WEMA trial site experiment

Methodological Choices	The WEMA Trial Site
Defining drought stress (water control)	The trials are planted in January/February and watered up to 45 days after planting (up until the onset of the flowering stage), at which point watering is ceased on the water-stressed trial (aim is that it should receive no water 2 weeks before and 2 weeks after flowering)
Baseline against which to measure efficacy	1) 13 rows of hybrids without transgene planted in same (water limited) conditions 2) Hybrids with and without transgene (total 26 rows) planted in well watered condition adjacent to water-limited site 3) 4 rows of non-hybrid in both well watered and water limited conditions
Number of years over which to evaluate efficacy	3-4
Metrics of efficacy	Days between male and female flowering; senescence of leaves; number of cobs; and yield (weight of shelled grain)

Although this is not the full extent of the trialling that would happen before commercial release, the trials produce important information on which a decision about the environmental release of the varieties (so that the trialling of the varieties can be expanded to the target agro-ecological zones) will be based. Essentially it informs a risk-benefit analysis that will be conducted by the NBA and KEPHIS. The trial represents a very controlled experiment within highly specific conditions that are not based on approximations of any particular agro-ecological zone, but rather on a set of conditions that are judged to 'moderately' stress the crop growth. Problematically, the extent to which conditions on these sites can be controlled is limited. In the 2011 trial, an unusual short rainfall event in March disrupted the controlled drought conditions and compromised the legitimacy of the outputs of the trial[68]. A limited number of objective metrics provide the basis of on which to judge the efficacy: days between male and female flowering, senescence of leaves, number of cobs, and yield. It represents a streamlined and 'efficient' process of trialling that perhaps reflects the culture of the private partners within the project more so than it does the breeding and crop trialling traditions of CIMMYT. Furthermore, and somewhat in contrast to CIMMYT protocols around public intellectual property, one of the senior CIMMMYT crop breeders working at the site informed me that 'the results of the trialling remain confidential' (DW5). This rule has apparently been implemented in order to prevent premature farmer excitement about the varieties several years before they are ready to be commercialised (DW8).

[68] Unpublished WEMA report on confined field trials submitted to the NBA, held in NBA archives

Interpreting crop trial results involves the making of assumptions about the robustness and applicability of outputs. One of the claims about the performance of WEMA varieties that has become institutionalised and cited in a number of project outputs is that:

> 'The maize varieties developed under WEMA are expected to increase yields by 25 percent under moderate drought' (AATF, 2010: 2)

In fact, the figure appears to be loosely based on some experimental research conducted by Monsanto in the United States (Castiglioni et al., 2008) and some studies of water-limited grain yields (Campos et al., 2005; Boyer and Westgate, 2004), references for which were given in the WEMA application to the NBA for permission to conduct confined trials[69]. Castiglioni et al (2008) present the results of a number of trials of transgenic CspB event maize (compared with its conventional hybrid) under water limited conditions (no rainfall for a span of 10 to 14 days immediately prior to flowering) in the American Midwest. Although the experimental transgenic yields were higher, they did not reach the 25 percent growth suggested by WEMA:

> 'Yield averages of CspB-positive plants as a group were significantly greater than controls, by 7.5% (P, 0.01). A number of individual events exhibited significant yield advantages as well; the best two performing events, CspB-Zm event 1 and event 2, demonstrated yield improvements of 20.4% and 10.9%, respectively.' (Castiglioni et al., 2008: 450)

Experimentation on different hybrids within water limited conditions, simulated by reducing water availability below optimum during the flowering and grain filling stages, has demonstrated yield losses of between ~10 and ~80 percent across the referenced studies, dependant on a range of environmental and maize genetic factors. Almost all of this field trial data comes from US field trials, using US varieties. It is unclear how 'moderate drought' is defined in quantitative water availability terms within the conversion of experimental evidence into the WEMA narrative (i.e. the appropriate yield losses that are being extracted from this research in the WEMA interpretation of it), and how much of the subsequent yield loss can be bridged by genetic improvement (i.e. how the research reported by Castiglioni et al has been interpreted). To convert this disparate evidence into a suggested yield improvement in WEMA varieties compared with conventional African hybrid counterparts is really an assumption-laden task. Estimates of yield improvement are almost impossible to make until there is an in-country evidence base; in Kenya this is limited to data from the Kiboko site trials, which are so far

[69] It is odd that it was in this application that I should first come across references to crop performance studies, as biosafety applications are predominantly about demonstrating safety, not efficacy.

inconclusive about the positive effects of transgenic hybrids compared to their conventional hybrid counterparts (anonymous personal communication).

Whilst the trialling of varieties may produce positive indicators of trait performance, there remains significant uncertainty about how this will translate into farmers' experiences of the varieties, when grown under the location-specific conditions and land management choices of their fields. This uncertainty may be reduced through decentralised and down-scaled trialling mechanisms, but there are trade-offs between achieving stream-lined impact-at-scale and addressing these micro-scale uncertainties. Furthermore, these uncertainties become overlooked within interpretations of trial data that profess a confidence in sweeping conclusions about percentage yield gains under generic (and undefined) conditions.

Ignorance about Socio-Economic Impacts

Beyond the performance of crop varieties, whilst some research has been conducted into farmer preferences and technology adoption, and in spite of confident claims about social benefits, understandings of the socio-economic impacts of DTMA and WEMA technologies are subject to some degree of ignorance.

As part of the DTMA project, CIMMYT has carried out a number of household level surveys of the socio-economics of maize farming and smallholder livelihoods. This research has highlighted the plurality of bases on which farmers make decisions, the socio-economic constraints on adaptation, and aversions to risk. Socio-economists at CIMMYT have conducted household research in a number of African countries as part of the DTMA project and this is work that has revealed barriers to adoption related to seed supply system challenges, agricultural extension capacity shortfalls, and farmer preferences for alternative pathways of change[70] (e.g. Muhammad et al., 2009, Doss et al., 2003, Langyintuo et al., 2010). Furthermore, CIMMYT research on the sociology of risk has pointed out that 'adoption of DTMA varieties is unlikely to occur in the absence of policies which address provision of incentives to farm inputs traders [and that] another reason for poor adoption is the difficulty that farmers face in accessing cash, as well as the aversion to risk of losing their investment in the maize crops' (Muhammad et al., 2009: 30). This research has led to the publication of a number of policy briefs advocating the importance of incentivising investment in new varieties by seed companies and suppliers, for example, through the growth of agricultural credit systems (e.g. CIMMYT/IITA, 2010). It has also

[70] See also, DTMA 'Characterization of Maize Producing Household' Reports, available at: http://dtma.cimmyt.org/index.php/publications?start=15

informed the efforts of seed systems and deployment operations teams, particularly within DTMA, to establish favourable production contracts with seed companies (DW3).

A component of the household survey research conducted by CIMMYT in Makueni and Machakos districts in 2007 asked participants to evaluate alternative pathways to improving livelihoods. The following is an excerpt from the research report (Muhammad et al., 2009):

> 'To increase agricultural production, 25.4% of the farmers said they would plant profitable crops, 22.6% said they would use recommended agronomic practices and 12.6% said they would adopt improved varieties... To reduce agricultural production risk, 10.3% of the farmers said they would plant more profitable crops... To increase food security, 36.6% of the farmers reported that they would improve the storage facilities they are using, whilst on the improvement of health status in the family, 31.4% of the farmers indicated that they would improve on nutrition and eat balanced diets… To reduce farm level risk, 40.9% of the households indicated that they would invest in education.'

In summarising this research, statements such as: 'the findings of this survey indicate that attributes of DTM varieties such higher yields *[sic],* better drought tolerance and shorter maturity periods relative to the currently marketed varieties currently in the market, are likely to lead to their more widespread adoption' (Muhammad et al., 2009: iv), by authors from KARI and CIMMYT, may be justifiable, but they undoubtedly overlook the stated preferences of farmers for alternative pathways of change and adopt a narrow interpretation of risk (as solvable through technology adoption rather than recognising potential introduction of risk through such adoption). The incompatibilities between the WEMA narrative and those of farmers revealed in Chapter Six are further evidence of this and are discussed more in following chapters.

As was evident from discussions with both social scientists and crop breeders within CIMMYT, the scope and role of social impact assessments within the DTMA and WEMA projects are clearly restricted (DW3, DW7) and findings are largely interpreted as contextual factors that need to be addressed in order to facilitate the adoption of DTMA and WEMA varieties, rather than bases on which to evaluate the appropriateness and viability of such pathways, to the frustration of some of the socio-economists in CIMMYT and the CGIAR:

> 'The socio-economic research is rich and detailed but can be sometimes peripheral to the breeding projects' (DW17)

The institutionalised DTMA and WEMA approach to interpreting impact assessments is to focus narrowly on the technical performance of the technology. Glover (2009: 33) explains that such an approach narrows the space for a 'consideration of the complex role it may perform in a farming system or, more pertinently, a focus on the original problems farmers actually face and the types of technical, institutional and socio-economic interventions that might help them overcome those challenges'. This approach, in which the socio-economic constraints of the system are framed out and considered subordinate to silver-bullet solution of technology-driven yield increases, is particularly evident in the delinking of CIMMYT's own findings about risk aversion in the technology adoption of smallholder farmers from assumptions about the adoption of WEMA seeds:

> 'Risk of crop failure from drought is one of the primary reasons why smallholder farmers in Africa do not adopt improved farming practices' (AATF, 2008: 4)
>
> 'It is not that the basic technology to increase maize production does not exist. It is that the tools are not consistently used, largely because the farmer is unable to invest in them due to lack of capital, or because she is unwilling to invest what little capital she has for fear of losing her investment to drought' (AATF, 2007: 1)
>
> 'Once they see the benefits, farmers will very quickly choose to plant' (DW9)

In proposing the introduction of a new technology to tackle problems of low yield and drought, the WEMA narrative finds itself contradicted by the description of a context in which it is exactly these problems that are driving farmers' unwillingness to invest in technology. However, when it comes to WEMA products, such concerns are ignored and there is an assumption that an overriding rationality will result in wide-scale investment and adoption.

As part of the IRMA project, CIMMYT (in conjunction with the University of Nairobi and KARI) conducted some surveys on the attitudes towards GMOs of consumers, farmers, and gatekeepers (millers and supermarkets) in the early and mid-2000s (later published in: Kimenju et al., 2011). The results revealed that farmer awareness of GMOs and biotechnology in general, was low (although it is not clear how 'awareness', a highly subjective term, was interpreted by the survey designers or respondents). The surveys also asked respondents to agree or disagree with statements about the risks and benefits of GMOs and found high agreement with many of the benefit statements and mixed opinion on the risks (from urban consumers and gatekeepers). Unfortunately there has been little work on updating and verifying this research (most of the surveys on which it was based are at least six years old and sample sizes (particularly for the gatekeepers surveys) were very small).

When it comes to the socio-economic impacts of new varieties and technologies, then, there is both an absence of information that has been collected, particularly through *ex ante* studies, and a selective use and interpretation of this sparse information, which seemingly underpins confident and evidence-based statements about impact.

Ambiguity and Values in Crop Breeding

In light of both uncertainty about the technical performance of crops and ignorance about the socio-economic impacts of the technology, claims about the need for and pro-poor nature of the technology and justifications for investment in the particular approach to crop breeding advanced in DTMA and WEMA, particularly justifications of the need to invest in techniques of modern biotechnology, represent ambiguous judgements.

The trajectory of developments in crop breeding techniques and technologies that are being advanced within the modern facilities and projects mentioned above, most agree, have seen crop breeding become increasingly efficient and effective. Investment in the development of technologies, such as doubled-haploid breeding (a multi-million dollar facility for which is being developed at the Kiboko site), are favoured amongst the science community, including an interview respondent from CIMMMYT, for the way that they contribute to 'improving the accuracy and efficiency of [plant] breeding' (DW5). Doubled haploid breeding, for example, provides the potential to create a homozygous output from cross breeding, something which conventionally takes six generations to achieve and at the expense of the strength and quality of the plant (DW2).

Genetic modification, a process by which an organism's genome is directly changed often through the insertion of a sequence of genetic material from a donor species, is a relatively novel technique within African crop breeding[71] and it is seen differently within the scientific community as an extension of, and, as captured in the explanation of an interview respondent from AATF, a 'quantum shift' (DW9) in, this trajectory of crop breeding. This respondent suggested that the utilisation of genetic modification will allow for exponential gains and facilitate not only the improvement of crops, but their optimisation:

> 'Genetic modification offers huge potential for crop breeders in terms of allowing for [the] use of a whole world of genetic material and therefore being able to find the best [material] possible' (DW16)

[71] South Africa was the first African country to permit the commercial production of a GMO (Monsanto-developed Bt cotton) and a subsistence crop GMO (Bt maize) at the beginning of the 21st century and, to date, only two more African countries have approved GM crop production (Burkina Faso (in West Africa) and Egypt (in North Africa)).

The AATF WEMA project manager, a fully-fledged member of the science community and owner of a suitably impressive crop breeding academic résumé, is conversant in the corporate language through which investments in highly technical and relatively novel breeding technologies is justified. He explains that modern biotechnologies have the potential to target a set of very specific traits in an efficient and cost effective way that by-passes a lot of the time consuming experimentation of more conventional crop breeding (DW8).

Actors such as Monsanto and AATF (partners in the WEMA project but not participants in DTMA) profess an unshakably optimistic narrative in regards to genetically modified crops that sits in contrast to the much more tempered claims of both KARI and CIMMYT. KARI has been working on the development of drought escaping and drought tolerant varieties since the establishment of the dryland research station at Katumani in the 1960s and CIMMYT have contributed to this programme in East Africa since 1980, utilising germplasm developed in Mexico since the 1960s. Whilst much of the early work centred on the development of open pollinated and hybrid varieties through conventional cross-breeding, CIMMYT has since pioneered a number of technical breeding techniques, inclusive of doubled haploid, quantitative trait loci (QTL) identification and marker-assisted breeding[72]. Since the mid-2000s, CIMMYT has been screening for optimum QTL in its germplasm lines and this has resulted in what one of their crop breeders described as a ‘very fast improvement in the stress tolerance of maize’ (DW4). Involvement in genetic modification, however, is a relatively new endeavour for CIMMYT (initiated by participation in the IRMA project in 1999) in comparison with its longer history of breeding.

CIMMYT participates in the IRMA and WEMA projects via a largely conventional role; in both cases it is the private sector actors who provide genetically modified material for cross breeding and, aside from adhering to national and institutional biosafety protocols for the transfer and handling of material (in 2002 CIMMYT developed its own ‘CIMMYT Biosafety Policy and Procedures on Genetically Modified Organisms’) and the biosafety measures at the trial site, CIMMYT operations differ little from its work with non-transgenic lines: running trials, evaluating traits and implementing breeding strategies.

In a position statement on genetically modified crop varieties, CIMMYT acknowledge that there are potential gains to be made through the technology, but see it as additional, and arguably

[72] The optimum quantitative trait loci (QTL) – positions on the DNA strand in which the linked genes are responsible for a particular trait – for the anthesis-silking interval (the period between pollen shed and silk emergence), which is an important determinant of stress-tolerance, and for grain yield have been identified in CIMMYT work conducted by Ribaut et al in the mid-1990s.

subordinate, to the 'conventional but novel' research programmes and non-seed improvements, in which it has been engaged over several decades:

> 'GM crops are not a 'magic bullet.' The agricultural productivity increases needed by humanity will not come solely from genetic modification technologies. Conventional but novel research programs—far and away the most significant source of gains in food crop yields worldwide—as well as improved farming techniques, training, improved local markets, better storage facilities, effective supply chains, and favourable agricultural policies are crucial. But for the world to increase agricultural production by almost 2% a year for the next 40 years, all resources and approaches must be marshalled, including GM technologies.' (CIMMYT Position Statement on Genetically Modified Crops[73])

Although CIMMYT has pioneered technological breeding techniques, and proclaims the efficiency benefits of techniques that speed up the process, there is a clear contrast between the grounded optimism that it places on genetic modification and the grand claims that are evident within the WEMA narrative.

The silver-bullet component of the WEMA narrative in particular is held much less strongly within CIMMYT and KARI than it is within Monsanto and AATF. This is in part a public-private difference. Whereas private sector actors are experienced in the necessity and skills of selling a product, the public sector actors have a background that is more research-oriented and less product-motivated. But the difference is also a product of the instinct of individuals to justify their own work. CIMMYT crop breeders have little involvement in the laboratory-confined process of genetic modification, but are much more familiar with the suite of in-field breeding techniques that they have long practiced and perfected, whereas the reverse is true of Monsanto, whose own short history of crop breeding has largely focused on the development of genetic modification technology. Both positions are value-laden and ambiguous.

The following section looks at how the uncertainties, ignorance and ambiguities within the knowledge generating and interpretations of the WEMA and DTMA projects are communicated in the projects' external interactions and outputs. It begins to discuss the implications of this communication for the opening up of crop breeding, crop trialling and socio-economic impact assessments to the alternative knowledges of other stakeholders, including the perspectives of farmers discussed in Chapter Six.

[73] http://intranet.cimmyt.org/en/about-us/policies/position-statement-on-genetically-modified-crop-varieties

Advancing the Narrative: Farmers, Consumers and Regulators

As multi-actor projects and, in the case of WEMA, collaboration between public and private partners, DTMA and WEMA interactions take the form of both internal negotiations of a unifying narrative of agricultural change and external communication of this narrative to other stakeholders. Examples of both of these types of interaction – firstly the internal negotiation of operations and narratives and secondly the public communication of the project – are described and discussed here.

AATF is the organisation responsible for brokering the relationship between public and private partners within WEMA and over several issues, particularly around the ownership of the knowledge and technologies produced through the collaboration. Intellectual property utilised within, and produced as a result of, WEMA activity, is protected through a number of negotiated agreements that particularly seek to protect future commercial interests and has inevitably required distinctions to be made between works carried out by the individual partners (DW9). This is somewhat in conflict with the public mandate of the CGIAR, and has resulted in a number of concessions and clauses:

> 'CIMMYT regards its research products as international public goods, and therefore strives to achieve the broadest possible impact from the outputs of its research and the results of its development activities. CIMMYT will publish the results of its research and development activities as broadly and freely as possible. However, CIMMYT understands that partnerships with the private sector may be necessary to access the best technologies or ensure the most effective delivery of CIMMYT's outputs to target resource-poor farmers… In the modern landscape of public sector agricultural science, it is understood that relationships with the private sector are increasingly necessary to ensure access to the best technologies, harness efficiencies in product development, and achieve maximum impact through effective delivery and deployment of research outputs. Moreover, CIMMYT acknowledges that private sector partnerships require downstream incentives that must be carefully and innovatively managed to support CIMMYT's goals of broadly disseminating know-how and research as well as delivering technologies to stakeholders that promote the alleviation of poverty, hunger and marginalization.' (CIMMYT Intellectual Property Policy[74])

According to CGIAR protocol, the work of CIMMYT is a public good and, as far as possible its public accessibility should be maximised[75]. However, in working with private partners, CIMMYT realises that it must necessarily compromise on the accessibility of certain outputs in order to protect the 'downstream incentives' of private partners. This means placing restrictions on the use of end intellectual property or withholding the release of property for an agreed period

[74] http://intranet.cimmyt.org/en/about-us/policies/cimmyt-intellectual-property-policy
[75] The CGIAR Principles on the Management of Intellectual Assets (http://library.cgiar.org/bitstream/handle/10947/2778/Background%20and%20explanation%20of%20the%20CGIAR%20Principles%20on%20the%20Management%20of%20Intellectual%20Assets.pdf?sequence=1)

(DW17). In the case of WEMA it means having to identify separate breeding programmes as the basis of germplasm ownership[76].

Monsanto and CIMMYT have agreed to give AATF the right to grant royalty-free sub licences to seed companies for the end products of the WEMA project (and this will include a controlled permission to 'sublicense inbred lines from AATF to make non-exclusive hybrids or sublicense individual inbred lines from AATF to cross with one of its own inbred lines to make producer-specific hybrid seed'[77]). However, for Monsanto, maintaining a protected ownership over the technology is key to protecting their commercial endeavours, as such recognition of the value of seed technologies beyond the WEMA remit (e.g. outside of Africa and for large farmers) has been written in to the WEMA Intellectual property policy:

> 'The technology used in the Project is expected to have considerable commercial value to larger scale farmers in and outside Africa, and the parties also intend to manage Intellectual Property so as to preserve and participate in that commercial value creation.' (WEMA Intellectual Property Policy[78])

Drawing a clear boundary between what is charitable and what is commercial can become problematic and there are inevitable clashes between the two activities. This is evident, for example, in WEMA's decision not to pursue research into the combination of transgenic drought and insect resistance as a stacked-trait in maize that is being developed for South Africa, something that it is planned for the other WEMA countries, because South Africa already has a large commercial market for Bt maize products that would be compromised by the WEMA project (DW8). The combination of insect and drought resistance is understood as crucial for the efficacy of the product as field trials have shown that healthy maize growing in a dry environment becomes a prime target for insects (DW4), and is a focus of CIMMYT breeding work in the second phase of the WEMA project, however Monsanto chose to protect its commercial interests at a cost to the charitable project in South Africa. A representative of the AATF described this is a 'disappointing, but necessary compromise' (DW8).

As described above, similar compromise is evident around data-sharing from, and the participatory nature of, WEMA crop breeding. There is a contrast between the WEMA confined field trials and its confidential trial results and CIMMYT's participatory varietal selection exercises of the AMS and other crop breeding programmes, in which emphasis is placed on the

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[76] WEMA Intellectual Property Policy (available at: http://intranet.cimmyt.org/en/about-us/policies/cimmyt-intellectual-property-policy)
[77] WEMA Project Collaboration document (http://beta.aatf-africa.org/userfiles/Wema-Summary-Collaboration.pdf)
[78] WEMA Intellectual Property Policy document (http://www.aatf-africa.org/userfiles/wema-ip-policy.pdf)

transparency of the process, data sharing, and the opening up, at an early stage, to a whole range of farmer-defined and locally-appropriate indicators. Arguably, within the WEMA project, particularly in relation to its GM component, there is a greater emphasis on the communication of the social benefits of the technology and public sensitisation, than in the participation of stakeholders in shaping the breeding programme and technology development.

Given the negative perceptions of GM technology, which have been socially amplified within Kenya as a result of media reports and misguided statements by high-profile politicians, there is a tendency for these public sensitization endeavours to present a selective message about the technical and social benefits and growing global adoption of the technology. This is particularly evident within the outreach efforts of ISAAA and AATF, such as the OFAB meetings and the BioAWARE programme. It is also evident in the outputs of the WEMA project, which are inevitably, at least in part, motivated by a need to justify investment in transgenic breeding to a sceptical public as well as project funders.

The claim to 25 percent yield gains, which, as explained above, is of dubious origin, has become a big part of the public discourse promoted by AATF. A number of assumptions and extrapolations made by Monsanto from a single set of controlled experiments have gradually become embellished within a WEMA narrative that depends quite heavily on the performance of the technology. A crop breeder in CIMMYT later explained that '25 percent is a target as opposed to an expectation' (CIMMYT email correspondence, November 2012), and another described it as an economically-based threshold target beyond which the project would become successful (DW2). The latter, in particular, recognised that in order for investment in genetic modification to be justified it must aim to achieve a productivity benefit that will be great enough to make the product attractive to seed companies and farmers to adopt. However, without communication of its political-, value- and incomplete evidence-base, the external communication of the narrative is highly misleading.

The promotion of a positive WEMA narrative of technical and social benefit is similarly made within regulatory debates and policy making, as is discussed in more detail in the following chapter. Through partners such as ISAAA and ABSF and through representation on regulation drafting stakeholder panels (many of Kenya's have been drafted by legal consultants from KARI), within Biosafety Committees and the National Biosafety Conference (which is financially supported by CIMMYT and AATF), WEMA is an influential actor within debates around biosafety regulation in Kenya (and beyond).

Regulatory requirements concerned with labelling and traceability, particularly where these translate into extra costs to be absorbed by the farmer or the consumer, could compromise the viability of the technology for its very target group (smallholder farmers). The inclination is for actors such as WEMA to advance a discourse of regulation that focuses on the social benefits of the technology and the facilitation of research, development and trade, closing down 'risk' to an object that is readily dismissed through scientific evidence (over which these very same actors conveniently hold a monopoly), such that the WEMA narrative is presented as objective and rational:

> 'Policy makers within the relevant government institutions and agencies should create an enabling environment and make science-based decisions that will facilitate the conduct of confined field trials and other biosafety regulatory steps that will eventually lead to commercialisation of WEMA seed varieties.' (AATF, 2008: 4)

In proclaiming this positive narrative and attempting to make persuasive arguments about the need for and benefits of the technology, there is a tendency for alternative perspectives to be delegitimised and the ambiguous, uncertain and ignorant nature of the knowledge that underpins the narrative to be denied and closed down. This is particularly the case within policy debate, and can be evident within the arguments of anti-GM lobby just as it is within WEMA and other biotechnology projects and proponents. This debate around GM regulation and how it is shaped by and simultaneously shapes the future of maize agriculture in Kenya is the focus of the following empirical chapter.

Conclusion

It is in the acceptance of particular narratives as motivation for action, that groups become organized into projects or institutions (Hajer, 1997, Smith, 2001, Fairhurst and Putnam, 2004). This provides a useful way of conceptualising the WEMA project in particular, which involves national and international public agricultural research institutions, private multinational technology companies, and global philanthropic foundations, all organised around the notion of providing a technological solution to a climatic problem.

The DTMA and WEMA narratives contain a careful construction of a 'global public good', such that it represents a unifying motivation for partners with different mandates. In satisfying the multiple and sometimes conflicting priorities of the project partners, there is a necessary politics around the definition of what goods and for whom. The achievement of a green revolution for Africa through a technological and scale-neutral good developed for the benefit of a public of smallholder farmers neatly brings together the impact at scale priorities of the BMGF and the CGIAR, as well as the charitable mandate of Monsanto's Sustainable Yields Initiative. However, it sits uncomfortably with Monsanto's own commercial priorities, necessitating a dissatisfactory manipulation of the concept of 'public' such that it instead constitutes those that do not represent a commercial market for Monsanto products. Similarly, the favouring of donor priorities for achieving targets across an aggregated public inevitably means that a 'global public' is approached as homogeneous, as opposed to diverse and contextualised

This negotiated concept of GPG, and the DTMA and WEMA narratives that it underpins, effectively acts to shape the way in which a whole range of project activities are framed and undertaken. Crop breeding focuses on optimal rather than appropriate technology development; crop trials take place in 'mega-environments' based on a static base level interpretation of ecological variability and in denial of the changing and diverse social, economic and cultural contexts for which the products are being developed; and socio-economic assessments focus on identifying the barriers to technology dissemination within the supply chain rather than on the preferences and pathways of farmers themselves. Evident in all three of these areas of operation – crop breeding, crop trialling and social impact assessments – is a common pushing of a technological solution that is assumed to steamroll its way through the uncertainty that emerges over time and from social, economic, political and cultural contexts, supposedly making such uncertainty redundant.

By framing out the uncertainty that emerges from diverse and changing social and economic contexts and framing out potential risks from the DTMA and WEMA narrative and acting within an institutional context that is resistant to such ideas, the narrative becomes almost self-fulfilling. Institutionally embedded interpretations of crop trial results and optimality focused evaluations of technologies of uncertain potential, inevitably reinforce the preconceived approach and vision of the projects and negate the need for engagement with alternative narratives.

In interpreting some of the results from the CIMMYT surveys on attitudes towards GMOs, Kimenju et al. (2005: 1074) recognise the ambiguous nature of the debate and conclude that:

> 'The core of the controversy over GM crops is the extent to which consumers perceive benefits from the technology relative to risks, as this will determine acceptability. Generally, people are appreciative of the positive benefits of the technology, although many are worried about potential negative effects. The government, the IRMA project, and a range of stakeholders face an important challenge in communicating the

> advantages *and disadvantages* of the technology to the general public' (emphasis added)

The suggestion that, in the face of uncertainty and ignorance about impacts of the technology, both advantages and disadvantages should be clearly communicated to the general public, is returned to in the final chapter, which discusses the importance of acknowledging and communicating incomplete knowledge.

The technical, performance, socio-economic impact and appropriateness of technologies are context-dependent effects and are, of course, uncertain and ambiguous. All too often, the legitimacy of a technology-centred narrative depends on closing the problem down to simple risk and benefit equation, in which these uncertainties and ambiguities are denied. The result, as in the case of WEMA, is that Kimenju et al.'s prescription of communicating openly about the potential disadvantages of the technology becomes neglected, even redundant, within its interactions with farmers and regulatory policy-makers alike. These interactions are, of course, crucial to the success of the WEMA/DTMA narrative. Technology developers certainly cannot expect farmers simply to adopt technologies on the basis of their word alone. The next chapter begins to reveal how this is true also of attempts to advance a WEMA narrative within technology regulatory debates, in which there are a number of competing narratives, some of which are not only incompatible with the WEMA narrative, but actually threaten the viability of the project.

Chapter Eight: Biosafety Regulation

Contested Narratives and the Kenyan 'GM Debate'

The focus of this final empirical chapter is the case of the regulation of modern agricultural biotechnologies in Kenya; a policy sector which explicitly shapes the use of technology and ultimately the viability of the WEMA narrative discussed in the previous chapter. Although the focus of this chapter is on a specific policy sector, it begins to show the way in which individual policies have agency in shaping agricultural futures, potentially creating delays in the technology pipeline that are incompatible with narratives of urgency around climate change impacts, and with ramifications for smallholder adaptation strategies. Using both retrospective and contemporary narrative policy analysis, the contestation over the content and nature of regulation is analysed. This analysis is applied to the policy debate over the establishment and implementation of Kenya's 2009 Biosafety Act, as well as the regulation of GMO labelling and a significant policy moment, Kenya's ban on the importation of GM foods, which together dominated the biosafety debate in 2012. Throughout the chapter it is argued that the contestation over biosafety regulation in Kenya has taken place within a context of the popularisation of a scientific evidence-based policy discourse. Within the GM debate, actors from all sides are increasingly claiming the legitimacy of their narratives on the basis that they are supported by objective evidence and simultaneously dismissing alternative arguments on the basis of their ignorance or ambiguity. In this chapter, the nature of knowledge that underpins the dominant arguments within biosafety and regulatory debates, from both pro- and anti-GM stakeholders, is unpacked, revealing uncertainty, ignorance and ambiguity and the politics around the closing down of these knowledge gaps. This closing down and attempts to delegitimise alternatives is evident at a number of points within a long history of biosafety debate in which the pro- and anti-GM lobbies interact with others. These interactions are the focus of the later part of the chapter.

The Context of Regulatory Debate and Policy Making

The National Biosafety Authority's first annual National Biosafety Conference took place in August 2012 at the Kenyatta International Conference Centre in central Nairobi, a towering building that has become emblematic of the capital's corporate community and is located between City Hall and the Office of the President. The conference opened, over two hours late, with a tedious half an hour of introductions by various people within the National Biosafety Authority, who each individually addressed, by name and title, the line-up of distinguished politicians and professors positioned behind the long decorated table on the stage at the front of the large hall. These introductions were building up to the formal address of the conference's delayed guest of honour, the Minister for Higher Education, Science and Technology, Professor Margaret Kamar. In her address, she told the audience about her first day in the Ministry explaining that it coincided with frenzied media reports that GMO maize was illegally entering the country. She described a chaotic situation within the Ministry in which different people were asking different questions unsure whether this was an issue about the health risks of GMO foods, the traceability of GMOs, or the policing of borders. In trying to make sense of this complex set of issues, she explains, 'I came to the Ministry and I asked one question… 'what do the scientists in Kenya say?''... Particularly within the open debate sessions of the conference, the multiple ways in which issues become framed became increasingly evident, and, just as in the opening speech, a model of policy that is dependent on the evidence of the scientific community was repeatedly advanced in response.

The gazetting of Kenya's Biosafety Act in 2009, which outlines the roles and responsibilities of a National Biosafety Authority to oversee applications for GMO-related activities, was the culmination of a process of co-evolution and conflict between the ongoing research practices of Kenya's bio-science institutions, which began with genetic modification trials on sweet potatoes in the early 1990s, and political debates over regulation. The development of both scientific practice and regulation regarding GMOs in Kenya followed an unusual trajectory in which guidelines of good practice, drawn up out of the necessity of placing regulatory boundaries on a rapidly developing scientific endeavour, acted as the reference point for the formalisation of regulations over ten years later. That fact that regulatory protocols were first established within the institutions of biotechnology research combined with the complex scientific nature of the technology, acted to legitimise the privileged position of experts in the drafting of the Bill. Particularly within internationally-supported biosafety regulation capacity building efforts, and somewhat in contradiction to the initial emphasis of the Cartagena Protocol on Biosafety, this discourse of scientific evidence-based policy has been particularly influential in Kenya.

Whilst these claims to scientific legitimacy have largely underpinned arguments from the pro-GM lobby about the need to minimise regulatory barriers to technology development, and this influence is evident within the final text of the Biosafety Act, alternative evidences have been drawn on by an anti-GM lobby that has advanced the counter argument. Furthermore, within recent debates over the labelling of GMOs and the ban on GM foods, arguments about the need for precaution and the protection of consumer choice have been justified by a challenging of the authority and completeness of scientific evidence. In the following section a brief history of regulatory debate and key actors in Kenya is outlined before moving to an analysis of the nature of knowledge within these debates.

The History of Biosafety Regulation

Genetic engineering research and the development of regulatory structures and guidelines in Kenya in the early 1990s were largely funded through the Dutch Government's Directorate General for International Cooperation. Although part of this programme involved the development of Kenya's 1998 'Regulations and Guidelines for Biosafety and Biotechnology in Kenya' within the National Council for Science and Technology (NCST; a government parastatal created within the Ministry of Education, Science and Technology), these regulations did not include mechanisms of legal obligation and responsibility and effectively acted to facilitate expanding research and development activity under institutional and informal good practice guidelines (Harsh, 2005; BS5).

It was the ratification of the Cartagena Protocol on Biosafety in 2003 that provided much of the impetus for Kenya to develop a more formalised system of national biosafety regulations (BS1). The Protocol had been widely ratified by the mid-2000s, with the notable exceptions of some of the largest GMO exporting countries (USA, Canada, and Argentina). A 'like-minded group' of African nations, who wished to protect their rights to restrict the entry of GMO products into their markets, represented a significant driving force behind, and an important contributor to the text of, the Protocol[79], which recognizes that concerns about process-related uncertainties may represent legitimate grounds on which to both interpret risk and reject biotechnologies. It also emphasizes the importance of detailed information exchange prior to countries consenting to the import of GMOs.

[79] South Africa is one of the only GMO exporting nations to ratify the Cartagena Protocol

Box 3: Timeline of key international influence in the development of Kenya's Biosafety Regulation

1993 Biotechnology Programme of the Netherlands Directorate General for International Cooperation begins to fund activities towards the development of a Biosafety Framework in Kenya

1995 The establishment of the WTO brings the Agreement on the Application of Sanitary and Phytosanitary Measures and the Agreement on Technical Barriers to Trade into force

1996 UNEP/GEF began demonstration project on facilitating development of National Biosafety Framework in Kenya

1998 **'Regulations and Guidelines for Biosafety and Biotechnology in Kenya' introduced**

\- Launch of phase 2 of UNEP-GEF project

1999 Establishment of Biosafety framework through UNEP-GEF support and continued support of Netherlands Directorate General for International Cooperation

2000 Kenya signs Cartagena Protocol on Biosafety

2001 African Union finalises the African Model Law (AML) on Safety in Biotechnology

2003 Kenya ratifies Cartagena Protocol on Biosafety

\- Establishment of the Programme for Biosafety Systems (PBS) with funding (14.8 million USD) from the United States Agency for International Development (USAID) through the International Food Policy Research Institute (IFPRI)

\- First full report of the Codex Alimentarius Commission *Ad Hoc* Intergovernmental Task Force on Foods derived from Biotechnology

\- African Union endorses the Africa-wide Capacity Building Programme in Biosafety which encourages the adoption of the African Model Law

2005 NEPAD and the African Union establish the African Panel on Biotechnology

\- ASARECA and ACTS begin the 'Regional Approach to Biotechnology and Biosafety Policy in Eastern and Southern Africa' (RABESA) initiative on behalf of COMESA

2006 **Adoption of Kenya's 'National Biotechnology Development Policy'**

\- The African Union Commission proposes an African Strategy on Biosafety and declares an African Position on GMOs in Agriculture

2007 **Finalisation and presentation to Parliament of the Biosafety Bill**

2008 Revision of the African Model Law (renamed African Model Law on Biosafety)

2008/9 **Acceptance and gazetting of the 'Biosafety Act'**

2009 Replacement of the National Biosafety Committee with the National Biosafety Authority, housed within the National Council for Science and Technology

2011 Publishing of 'Environmental Release'; 'Import, Export and Transit'; and 'Contained Use' Regulations

2012 Publishing of 'Labelling' Regulations

- Ministry of Public Health and Sanitation announce a national ban on the importation and consumption of GM foods

A number of capacity building mechanisms were built into the Cartagena Protocol (Article 22) and funded through the United Nations Environment Programme/Global Environmental Facility (UNEP/GEF) in order to assist countries in developing biosafety regulations and capabilities for processing, analysing and interpreting scientific, environmental, and legal information. The NCST had participated in the UNEP/GEF demonstration project on facilitating the development of National Biosafety Framework since 1996, and continued to benefit from programmes that supported its implementation of the Cartagena Protocol. The UNEP/GEF 2003 Guide for the implementation of national biosafety frameworks states in its introduction:

> 'The objective, scope and structure of regulatory regimes for biosafety vary from country to country. The objective of some regulatory regimes is exclusively focused on environmental safety, whereas the objectives of other regulatory regimes have broader objectives. Some regulatory regimes have a narrowly defined scope, such as releases into the environment of GMOs, whereas other regulatory regimes have a more encompassing scope, such as the contained use, release into the environment, placing on the market, and import and export of GMOs and GMO products.... there is no such thing as the perfect 'one size fit all' template for a regulatory regime for biosafety. It very much depends on countries' existing regulatory and administrative structures and practices and its international obligations to decide what an appropriate regulatory regime for biosafety can be.'[80]

The Biosafety Act describes a risk assessment and approvals procedure coordinated through the NBA, for any activity within Kenya involving the use of genetically modified materials, such that applications for permission to conduct activity will be independently reviewed according to stringent safety guidelines, and that there will be an opportunity for public concerns to be submitted in response to applications. The Biosafety Act makes provisions for different aspects of GMO development and commercialisation to be regulated through specific guidelines to be appended to the Act. In 2011, three sets of regulations governing (1) contained use, (2) environmental release, and (3) import, export and transit, were passed into law.

The fourth of these regulatory documents, concerning the labelling of GMO products for public consumption, was finalised and agreed upon in May 2012 and was translated into a Kenya Bureau of Standards (KEBS) standard (DKS 2225: 2012) for the labelling of GMO products in July[81]. The regulations were created by the National Biosafety Authority (under the responsibilities assigned to them through the Biosafety Act) through a legal consultant, Betty Kiplagat from KARI, and the consultant's initial draft, which was informed by a review of labelling regulations elsewhere, underwent an internal review process (through the NBA technical team) and consultation with stakeholders (invited by the NBA) across two sessions, before being

[80] http://www.unep.org/biosafety/Documents/Impl.Guide-RegReg.pdf (accessed on 13/10/13)
[81] A fifth regulation, regarding 'handling, storage and packaging' is currently being drafted within the NBA

submitted to the minister and the attorney general's office for gazetting (BS1). The process by which these regulations, and the subsequent standard, came about, including controversies over the use of standards from overseas and ongoing debate about consumer rights and the implications of labelling for the trajectory of technology development, offer a clear illustration of how alternative framings of technology and regulation shaped opposing policy narratives.

The stated objective of the 2012 labelling regulations is two-fold:

> '(3a) to ensure that consumers are made aware that the food, feed or product is genetically modified so that they can make informed choices; and (3b) to facilitate the traceability of products to assist in the implementation of appropriate risk management measures where necessary'

Essentially, the labelling of GMOs is both a means of informing consumers about products and protecting their right to choose whether or not to consume them, as well as mechanism for recalling products if unanticipated future risks or objections present themselves. In close conformance with the EC legislation, the Kenyan regulations lays out a number of legal obligations, to be placed on the 'operator'[82] in order to meet these objectives, specifically they include ensuring that any food, feed or ingredients containing more than 1% of a safety approved genetically modified material (by weight) must have the words 'genetically modified' printed on a label or displayed at the point of sale, and include additional information if '(7(2f)) the genetic modification raises significant ethical, cultural and religious concerns regarding the origin of the genetic material used in genetic modification'.

Millstone (2000) has discussed the significance of labelling regulations in determining the viability of GM foods in the UK, and whilst he recognises that labelling need not exclude the technology from society, it places a burden on technology developers to ensure that the public benefits of the technology outweigh the perceived risks of consumers that, through labels, are offered the choice to reject them. This explains why, both the rationale and the content of the labelling regulations have been criticised and disputed by the technology's proponents. The stringency of the threshold percentage of GMO content has been criticised, particularly within National Biosafety Conferences and OFAB meetings, as has the practicability of enforcing the regulations and their implications for the viability of GM for smallholder farmers. As is discussed later, much of this contestation is centred on the scientific basis for the regulation.

[82] The 'operator' is defined in the regulations as 'a natural or legal person who places a product on the market at any stage of the production and distribution chain, but does not include the final consumer' (p.326 Kenya Gazette Supplement no. 48, 25th May 2012)

In November 2012, a significant policy moment occurred that derailed the trajectory of GM technology development in Kenya and changed the political landscape of regulation, potentially reopening the policy window that the gazetting of the Biosafety Act appeared to have closed. On 21st November 2012, Beth Mugo, then Minister for Public Health and Sanitation, announced that the Kenyan Government had supported a motion presented by the Ministry of Public Health to ban the importation and consumption of genetically modified foods with immediate effect. In her public address the Minister said:

> 'The decision was based on genuine concerns that there has not been adequate research done on GMOs, some countries have banned the importation of GMO foods into their territories on account of food safety and the welfare of their own citizens. It is for this reason that the Ministry of Public Health and Sanitation in collaboration with other organs of the government has decided to commission a study into this issue in order to appropriately advise the government on the way forward regarding the importation of GM foods'

The official cabinet statement further adds that:

> 'The ban will remain in effect until there is sufficient information, data and knowledge demonstrating that GMO foods are not a danger to public health.'

The decision was taken without the consultation of the National Council for Science and Technology or the Ministry of Agriculture, who had been the most instrumental Ministries in the shaping of biosafety law for more than a decade (OF4). The Ministry of Public Health had been absent, and to some people's minds excluded, from the policy process around the Biosafety Act and subsequent regulations, and a respondent suggested that the ban was born out of battle for an inter-Ministry battle over the ownership of biosafety (BS15). The ban has been a controversial and unexpected move from a Ministry that has been largely absent from the design and implementation of biosafety regulation. It is thought to have predominantly been a response to a controversial study into the health effects of GMO consumption, described below. Although the ban does not prevent the on-going development of agricultural biotechnologies, for those concerned with food products it means that there is currently no prospect for commercialising an end-product.

The cases of the Biosafety Act, the labelling regulations, and the ban on the importation and consumption of GMOs, and the contested and incomplete nature of the knowledge bases that shaped them, are analysed in more detail in the following section.

Negotiating Incomplete Knowledge in Biosafety Policy

Throughout the contested politics of GMO regulation in Kenya, and from all sides of the debate, justifications for arguments are made by reference to incomplete knowledge. The ban on importation and consumption of GMOs, for example, responded to evidence about the health impacts of GMO consumption that continues to be associated with significant uncertainty, and ignorance persists amongst different groups (including consumers) about the benefits and risks of the technology. As such, interpretations of evidence and arguments about the best thresholds for labelling, the sufficient numbers of years of product trialling, and even the justifiability of a blanket ban itself, are inevitably based on value judgements and political motivations.

Uncertain Evidence Bases and GMO Health Risks

The blanket ban on the importation and consumption of GMOs announced by the Ministry of Public Health and Sanitation in November 2012, followed a similar decision taken by the Russian government, and it is thought, particularly amongst OFAB participants, to have been a response to a high-profile peer-reviewed study at the University of Caen (in France), led by Gilles-Eric Séralini, which tested the effects of the consumption of NK603 (round-up tolerant) maize on rats[83]. The study was conducted over a period of two years and found that test groups were more likely to develop tumours, and at earlier stages, than the control group. Based on the findings of the study, the authors make the following evaluation:

> 'In females, all treated groups died 2–3 times more than controls, and more rapidly. This difference was visible in 3 male groups fed GMOs. All results were hormone and sex dependent, and the pathological profiles were comparable. Females developed large mammary tumors almost always more often than and before controls, ... Males presented 4 times more large palpable tumors than controls which occurred up to 600 days earlier. Biochemistry data confirmed very significant kidney chronic deficiencies; for all treatments and both sexes, 76% of the altered parameters were kidney related. These results can be explained by the non-linear endocrine-disrupting effects of Roundup, but also by the overexpression of the transgene in the GMO and its metabolic consequences.' (Séralini et al., 2012: 4221)

However, critics have been vociferous in their criticism of the methods, approach and analysis of the Séralini study. In the Séralini paper itself, some of the methodological choices are compared to those used in a toxicity study of Roundup-ready maize conducted by Monsanto (Hammond et al., 2004) and the non-mandatory regulatory in vivo tests for GMOs outlined by the OECD (OECD Guideline 408). This comparison apparently (according to the authors) demonstrates the robustness of the Séralini methodology (i.e. the greater number of samples used and variables

[83] N.B. the paper was retracted by the Editor-in-Chief of 'Food and Chemical Toxicology' in November 2013

measured). However, many of Séralini et al.'s methodological choices have been strongly criticised leading to the study being widely discredited. A statement made by the European Food Safety Authority (EFSA) in the EFSA journal explains a number of these criticisms made in reviews by member states and concludes that 'the study as reported by Séralini et al is of insufficient scientific quality for safety assessments' (European Food Safety Authority, 2012: 9). For example, it is argued that: one control group is not sufficient to serve as control for all of the variables tested within the other group; 10 rats of each sex per control groups is not sufficient for testing carcinogenicity; that the particular strain of rats used is highly prone to spontaneously developing tumours over their lifespan. Furthermore there is clear ambiguity in the interpretation of the results, with EFSA members arguing that, contrary to the claims of Séralini et al., there is no clear dose-response relationship for the reported parameters and 'that the mechanistic assumptions related to the modification of secondary metabolism are not supported by the results' (European Food Safety Authority, 2012: 7). Moreover, the Séralini group has been particularly uncommunicative in response to their critics, inevitably resulting in widespread scepticism about their methods and motives and, as a result, a number of anti-GM NGOs, such as Greenpeace, have been quick to disassociate their own arguments from the study.

The Kenyan Government has not directly cited the study in formal communications about the ban, but it does refer to insufficient knowledge about the dangers of GMO consumption to public health. In spite of being widely criticised, the Séralini study has been politically influential, not because it has persuaded the scientific community, governments, regulators, or even publics about the health risks of GMO consumption, but because it has called into question an apparent scientific consensus about safety, highlighting that different approaches to safety testing might produce different results and that, as such, there remains significant uncertainty about health effects.

Whilst the contained use regulations, which require applicants to provide evidence of allergenicity and toxicity by reference to peer-reviewed laboratory studies, offer the primary mechanism through which health risks of a GMO are assessed, the traceability conditions within the labelling regulations offer a secondary mechanism by which products can be recalled if unforeseen negative impacts present sometime after they are placed on the market. It is a precautionary measure based on an understanding that in spite of safety testing at the point of application for contained use, and confident assertions by the National Biosafety Authority that ‘if GMOs are approved by the NBA then they are safe’ (Dr Willy Tonui[84] Interview on Citizen TV, 2013), some degree of uncertainty about the real world and long-term impacts of the technology persist.

Paternalistic Regulation in Response to Public Ignorance

The early years of Kenya’s biotechnology development, which took place largely within a ‘legislative vacuum’ (Wakhungu and Wafula, 2004: 43), set an important precedent in the development of biosafety regulation. A lack of state structures to govern this activity resulted in those institutions involved in research and development (largely through internationally-funded public-private partnerships) being afforded a certain amount of regulatory autonomy.

> ‘Formal governance of agricultural biotechnology in Kenya—i.e. national institutional and policy developments—has been loosely coordinated and largely reactive, both in terms of biosafety and in terms of setting national priorities. Governance of biotechnology has thus been largely informal with strategic decisions being made mainly outwith state mechanisms’ (Harsh, 2005: 662)

Furthermore, low levels of understanding about the potential risks and benefits of biotechnology outside of these institutions, meant that there was an inevitable dependence on the expertise and experience of biotechnology developers in informing the regulatory development process (BS5, BS11). In the Cartagena era and the push for more formalised regulatory frameworks, those institutions found themselves in the privileged position of being the drivers of this regulatory development, both in terms of representation within the NCST and as coordinators, partners and participants in UNEP/GEF and PBS programmes.

A coalition of governmental and non-governmental partners, agricultural biotech research institutions and development partners were highly influential in the drafting of the Biosafety Bill and made a coordinated and well organised effort to promote both the Bill and the technology, primarily to those politicians with the power to pass the bill but also to the public through outreach programmes. ISAAA AfriCentre, a key player in the coordination of these activities, reflected on the process in their 2010 report entitled ‘Developing a Biosafety Law: Lessons from the Kenyan Experience’:

> ‘A series of consultative meetings facilitated by ABSF and ISAAA AfriCentre brought together the African Agricultural Technology Foundation (AATF), Africa Harvest, and the Centre for Biotechnology and Bioinformatics (CEBIB) of the University of Nairobi,

[84] Chief Executive of the NBA

> PBS, KARI, the private sector under the Seed Trade Association of Kenya (STAK, regulatory agencies under the aegis of NCST and the Ministry of Agriculture... Establishing a coalition of interested individuals and organizations is [a] key step. Identify allies in the government, the community, the media, donors, private sector and farmers as well as potential opponents. In the Kenya case, the Biosafety consortium started by calling for consultative meetings to map out organizations and individuals who were interested in issues of biotechnology and biosafety and invited them for partnership. With contributions and commitment to support the process, funding from themselves, the government of Kenya, UNEP-GEF, USAID and several other development partners form both public and private sector, they formed a closely knit biosafety consortium that successfully coordinated the development of the Biosafety Act 2009 through sharing of synergies.' (Karembu et al., 2010: 4 & 55)

Through this consortium, or coalition, an intensive process of promotion of the Biosafety Bill was undertaken, including organised tours for MPs to visit biotechnology research stations in South Africa, a documentary entitled 'Biotechnology: We have the Capacity' and other promotional media that were shown to the Parliamentary committee on Education, Science and Technology (Karembu et al., 2010), and in 2008 the National Biotechnology Awareness Strategy (BioAWARE) was established. Kingiri (2010) identifies three ways in which 'experts' were able to drive policy: (1) as institutional and national biosafety committee members; (2) as members of the biosafety bill drafting committee; (3) and as coordinators and moderators of public debates and awareness campaigns.

This expert ownership over the development of the Biosafety Act was justifiable because of the lack of awareness and understanding of what genetic modification is, and how biosafety testing can be conducted and interpreted, outside of the institutions that were already involved in developing the science. There is a limited pool of experts that the NBA can draw on in the assessment of biosafety applications, and they are inevitably drawn from a fairly close-knit community of crop breeding experts (described in the previous chapter), because outside of this community there is insufficient knowledge about how to assess and interpret these highly technical documents.

Rachel Shibalira, a legislative drafting consultant involved in the development of the Biosafety Act, at the OFAB meeting in May and referring to labelling regulations, questioned the authority of an ignorant public to make their own decisions about safety on the basis of labels, suggesting even that labelling undermines the expert authority of the NBA when it comes to safety testing:

> 'It puts the role of the National Biosafety Authority into question, they have already done the risk assessment and they have already shown the product is safe, and yet we put it on the shelf and say watch it because we still have some concerns… so it puts NBA

> into question… the NBA is supposed to be the one that looks at the safety and decides if it is safe to use' (Rachel Shibalira, OFAB, May 2012)

In theory, an evidence-based judgement is best made by those with access to the evidence, and so the NBA would be much better placed to make a decision about the risks of consuming a product than the consumer. Moreover, from this perspective it is argued that labels not only respond to an understanding of biotechnology as a social risk, but they can also be seen as promoting such a framing, essentially exacerbating the risk perceptions of ignorant consumers. As one participant put it:

> 'If my mother goes into the supermarket and is faced with the choice between flour that is not labelled and that which is labelled as containing GMOs, she may think 'why is that label there' and be suspicious of it – she will see no reason to choose that one' (Anonymous participant, OFAB, June 2012)

Acknowledgement of public ignorance about the science of genetic modification has inevitably justified an expert ownership over regulation and even called into question the appropriateness of permitting consumer choice. As is discussed later in this chapter, recognition of ignorance outside of expert communities has shaped approaches to public engagement and outreach around biosafety issues. However, as the case of uncertainty within scientific studies of safety suggests, knowledge within expert scientific communities is similarly incomplete and, as such, regulatory policy making is inevitably ambiguous.

Value Bases and the Ambiguous Nature of Regulation

The Programme for Biosafety Systems (PBS) was established in 2003 with funding (14.8 million USD) from the United States Agency for International Development (USAID) through the International Food Policy Research Institute (IFPRI), to assist in capacity building and the development of biosafety regulations in developing countries through national advisory committees and has largely taken up the mantle of the UNEP/GEF projects since the mid-2000s. USAID is a federal government agency that has operationalised, since its establishment in 1961, a remit of building US international relations, promoting foreign policy interests, and furthering US economic growth through international trade[85]. A stated goal of USAID is to promote agricultural biotechnology and 'integrate GM into local food systems'[86], and it is explicit about its desire to provide US-based biotechnology companies (which themselves provide financial support to USAID) with opportunities to 'transfer technology' to developing countries.

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[85] www.usaid.gov/about_usaid/ (accessed on 23/9/13)
[86] 'USAID Announces International Biotech Collaboration' http://www.fas.usda.gov/icd/summit/2002/statearchive/USAIDbiotech.htm (accessed on 4/11/13)

The Cartagena Protocol Article 26(1) states:

> 'The Parties, in reaching a decision on import under this Protocol or under its domestic measures implementing the Protocol, may take into account, consistent with their international obligations, *socio-economic considerations* arising from the impact of living modified organisms on the conservation and sustainable use of biological diversity, especially with regard to the value of biological diversity to indigenous and local communities.' (emphasis added) (Secretariat of the Convention on Biological Diversity, 2000: 19)

Whilst the Cartagena Protocol created space for precautionary regulation and encouraged a nationally appropriate and autonomous approach to managing social risks, as the policy debates have evolved in Kenya and external influences such as the PBS have increasingly shaped regulatory development (BS6), the implications for regional innovation and international trade of the inclusion of cautious text within policy documents, have been highlighted in arguments against the adoption of Cartagena principles. Tensions between the WTO's Sanitary-Phytosanitary (SPS) Agreement (which came into force with the establishment of the WTO in 1995) and the Cartagena Protocol on Biosafety (signed by Kenya in 2000) have been the subject of substantial academic enquiry (Isaac and Kerr, 2003, Oberthür and Gehring, 2006, Sydnes, 2008, Safrin, 2002). The SPS agreement adopts a clear end-product-based approach to defining technology and with a primary interest in trade tends towards a social benefits focus. Whilst the agreement allows for countries to set their own standards for biosafety, it effectively limits the agency of states to block trade on the basis of 'non-scientific' objections or anything more sustained than 'temporary' precaution. The SPS agreement states that safety concerns may only be based on 'explicit scientific evidence' and any trade restrictions be proportionate to the evidence-based level of risk presented by the commodity. Temporary precaution is permitted within the WTO agreement, where current evidence is 'insufficient', under the condition that members seek to carry out a 'more objective assessment of risk… within a reasonable period of time' (Article 5.7).

This idea of an objective assessment and the closing down of GMO regulation to technical studies of the health and environmental impacts of particular products, denies a principle which was fundamental to the Cartagena Protocol, that uncertainty exists within such studies and that their interpretation is ambiguous. Cartagena protected the rights of nations to make judgements about GMO policies on the basis on their own combinations evidence and their own negotiations over how to interpret it. A denial of this ambiguity and the notion that there is one rational decision to be made about GMOs that is common across all nations is facilitating of international trade. The WTO, along with the main GMO-exporting countries and many of the regional African trade organisations (e.g. COMESA) and research and development groups (e.g. ASARECA), favour an international (or regional) harmonization of regulatory standards, in which transboundary movement legislation is standardised and, consequently, administrative processes are simplified and made more efficient (Newell, 2003). Therefore, whilst the argument for a reductionist and objective approach to regulation is presented as an apolitical argument, driven by scientific findings, it in fact has a highly political motivation of facilitating trade. This is an example of how judgements about how regulation should be framed are inherently political and ambiguous.

One of the key policy debates that has characterised the drafting of, and contestation over, the Biosafety Act, and is essentially a question of how regulation is framed, is over the inclusion of obligations on the National Biosafety Authority to take socio-economic impacts into consideration in the assessment of biosafety applications.

In many ways, the call for the greater inclusion of socio-economic considerations within regulation can be associated with the advancement of a value-based narrative of regulation, as it attempts to broaden out the idea of biosafety beyond those issues, such as health, over which scientific evidence holds somewhat of a monopoly, and instead incorporate more value-laden concepts such as well-being and sustainability.

A non-scientific basis for assessment was seen as problematic within the drafting of the Bill and largely discouraged through the Common Market for Eastern and Southern Africa (COMESA) Regional Approach to Biotechnology and Biosafety Policy in Eastern and Southern Africa (RABESA) project as well as within PBS guidelines. RABESA is a trade-focused initiative motivated by a USAID-funded study that highlighted the implications of restricting GMO trade between COMESA countries. The initiative is led on behalf of COMESA by ASARECA's Policy Analysis and Advocacy Programme, ACTS, ISAAA and PBS through financial support from USAID. In its first phase, RABESA undertook a number of studies on the impact of the regional adoption of GMOs on farm incomes, commercial exports and the delivery of food aid, concluding that 'COMESA-member countries could harness substantial benefits from the adoption of genetically modified insect-resistant varieties of cotton and maize... [and] there is currently little or no GMO-associated risk to agricultural export incomes' (Wafula et al., 2011: 2). RABESA advocates for a harmonization of biosafety policy across the COMESA countries in order to encourage resource sharing, improve the cost-effectiveness of adoption, and facilitate the movement of trade and food aid.

IFPRI have published a number of policy notes and guidelines on the subject of including socio-economic impacts within biosafety assessment, and though careful not to reject socio-economic assessment in principle, these documents often present one-sided warnings about the costs, challenges and negative implications of adopting such assessments, whilst at the same time using the opportunity presented by a discussion of socio-economics to emphasize the socio-economic benefits of GMOs:

> '...if biosafety regulatory frameworks do not clearly define the inclusion of socio-economic considerations or such considerations become an insurmountable hurdle, the result will be the reduction of potentially valuable technologies to farmers and consumers. Unreasonable regulatory delays or uncertainty can affect negatively the stream of societal benefits derived from the adoption of GE crops as developers tend to invest less in such environments or shift to nonregulated technologies... Inclusion of socio-economic considerations in a biosafety assessment in any of the modalities discussed in the paper, especially when the process does not clearly define the modality of inclusion, can increase the cost of compliance with biosafety regulations. If this is the case, then inclusion of socio-economic considerations may become a significant 'barrier to entry' for some developers.' (Falck-Zepeda and Zambrano, 2011: 191-192)

Concerns that social risk assessment will have an impact on trade and attempts to exclude social risks from the framing of GMOs are evident in stakeholder workshops and public sensitization campaigns (see below), and narratives of science- or evidence-based regulation is employed as an effective tool in the dismissal of socio-economic considerations.

Socio-economic considerations were not excluded from the final text of the Biosafety Act. Article 29 of the Biosafety Act states that:

> 29. (1) In determining an application, the Authority shall take into account:
> (a) the information submitted by the applicant;
> (b) such information and conditions as may be submitted by the relevant regulatory agency;
> (c) the risk assessment report;
> (d) any relevant representations submitted by members of the public; and
> **(e) socio-economic considerations arising from the impact of the genetically modified organism on the environment**

However, the extent to which this is realised as an obligation by the NBA is unclear. A discussion with a representative of the NBA revealed that he felt that such assessments were 'outside of the scope of biosafety' (BS15). The framing out of socio-economic considerations from early and institutionalised discussions of biosafety continues to be reflected in the ways in which it is conceptualised within regulatory practice. By contrast, the 2012 labelling and traceability regulations reflect a value-based precaution that protects the choices, and legitimises the non-expert knowledges, of farmers and consumers within a biotechnology future, no matter whether the basis for these choices are related to health impacts or reflect concerns about socio-economic impact. Acceptance of the role of value judgements and choices within biosafety remains ambiguous. Whilst the history of the Biosafety Act is one in which debate has been closed down to consideration of health and environmental impacts thus sustaining expert ownership over regulation, on the basis that consumers and publics are ignorant of the science of biosafety, the labelling regulations represent a recognition of scientific uncertainty and protect the rights of consumers to make value judgements about GMOs on the basis of their own incomplete knowledge. The following section looks in more detail at the way that stakeholders within these regulatory debates interact and communicate with each other and how different knowledges become privileged, integrated or excluded within regulatory policy making.

Participation in Regulatory Policy Making

UNEP/GEF, PBS, and the NCST, compatible with the Cartagena Protocol, advanced a discourse of public participation throughout the process of developing the biosafety regulatory framework in Kenya, but the extent to which this was achieved in practice was, in some respects purposefully, limited. Opposition to the Bill was largely advanced through a coordinated coalition under the collective name Kenya GMO Concern Group (KEGCO). The group was made up of a number of civil society groups and national and international environmental and agricultural organisations including: Action Aid International Kenya, Africa Nature Stream, Ecoterra, Greenbelt Movement, Kenya Small Scale Framers Forum, Kenya Organic Agriculture Network, and Participatory Ecological Land Use Management (BS3). The group challenged the 2004 draft Biosafety Bill on the grounds of human rights violations and the capacity and competence of regulatory agencies as well as pointing to concerns about incomplete evidence about the health risks of GMOs, they also organised a number of public protests against the introduction of GMOs to Kenya in Nairobi and Kitale (BS3, BS5). The Kenya Biodiversity Coalition also lobbied members of parliament to oppose the 2008 Biosafety Bill by arguing that its drafting lacked public participation. The group, in partnership with a select group of MPs, had contributed to the drafting of an Alternative Biotechnology and Biosafety Bill which was presented to the Parliament in 2008. The Alternative Bill had a much more precautionary nature and a broader (and largely impractical because of its scope) process-based understanding of the object of regulation as 'artificially modified' organisms. It also called for socio-economic impacts to be considered at all stages of the process (including contained laboratory trials). The Alternative Bill, however, had minimal political impact and was quickly rejected within government.

Harsh (2005) argues that the coalition of actors involved in the development of the Biosafety Bill and the coordination of its consultation, had the power to control and contain the participation of opponents within drafting workshops, resulting in the eventual adoption of a Biosafety Act that was largely unchanged over a 5-year period of stakeholder consultation, parliamentary debate, and protest. Stakeholder workshops organised by the developers of the Biosafety Bill were often the arenas in which opposing pro- and anti- alliances did battle over regulatory policy. The following excerpt from the minutes of a comment and response session from a workshop conducted in July 2007 by the National Council for Science and Technology (NCST), demonstrates how such workshops became an exercise in defending the framing of biosafety regulation adopted by the Bill, rather than an opportunity for participatory input. The session followed a day of presentations on the Bill by representatives from the NCST, Ministry of Science and Technology, and KARI. In the introductory remarks Dr Miriam Kinyua from Moi University (who later became appointed as chairperson of the National Biosafety Authority), clearly not reluctant to attempt to frame the discussion herself, 'reminded the participants that the green revolution passed Kenya by and there is need to look objectively at biotechnology so that we are able to reap the benefits of this technology'. The task-force panel was made up of representatives from ISAAA, CEBIB, Africa Harvest, University of Nairobi, and NCST:

> **Comment (from Africa Nature Stream):** The Bill will be used to open the Kenyan market to GMOs
> **Response from the Panel:** The objective of the Bill is clear: to regulate GMOs
>
> **Comment (from Kenya Biodiversity Coalition):** Small scale farmers have not been involved in the preparation of the Bill
> **Response from the Panel:** The process began in 2002 and 15 stakeholder meetings have been held since then. Also, consistent with Kenyan laws, the Bill was published for public comment within the requisite 21 days.
>
> **Comment (from Kenya Organic Agriculture Network):** The number of Farmers on the National Biosafety Board should be increased
> **Response from the Panel:** For a Board with a total membership of 16, one farmer representative is sufficient.
>
> **Comment (from Action Aid):** Clause 7 does not address food and livelihood security
> **Response from the Panel:** This is a policy issue outside the scope of the Bill.
>
> **Conclusion (in the meeting report):** Following a thorough review of the stakeholder comments above, the taskforce does not see the need for any further amendments to the Bill

Whilst much of the public participation and opportunities for input into the Bill happened through open fora in Nairobi and a 21 day period of publication for public comment, this came almost four years into the drafting process of the Bill and over fifteen years since genetic engineering research and the development of the Regulations and Guidelines for Biosafety and Biotechnology had begun. At this stage, key framings of the technology and the regulation had been well established and public input and influence (at least for those members of the public with the awareness and means to access the published draft and return written comments) was limited to altering the finer details of the Bill's text (BS3, BS10).

Frustrations over a similar situation of limited consultation were expressed with regards to the drafting and development of labelling regulations, this time coming from representatives of biotechnology institutions, including from the AATF. At a workshop held by the Open Forum on Agricultural Biotechnology and the Kenya Bureau of Standards (KEBS) on Kenya's labelling regulations in Nairobi in May 2012, representatives of biotechnology research institutions took issue with the National Biosafety Authority's 'lazy' practice of adopting the 'inappropriate' regulations utilised in Europe. The EC Regulation 1830/2003 on the traceability and labelling of genetically modified organisms, on which much of the initial drafting of the regulation was based, sets out a mandate of both protecting the rights of consumers to choose for themselves whether or not they consume GMOs and providing a measure against potential future risks of the technology and it applies to produce with a GMO content 1% or higher.

To the evident frustration of those at the OFAB meeting, discussions predominantly took place retrospectively, and consultation came far too late in process for the core debates to be meaningfully addressed. As such, discussion often centred on what the labelling threshold should be rather than the rationale behind labelling (BS6). The threshold issue is largely a technical one, and GM percentage thresholds for labelling have primarily been determined by the capabilities and accuracy of detection technology, and this is likely to become increasingly irrelevant as technical capabilities improve (Millstone, 2000). That this issue has become central to consultations and debate of labelling is indicative of the extent to which such consultation has been marginalised within the broader regulatory agenda setting.

In his outline of biosafety legislation in Kenya at the NBA National Biosafety Conference, the NBA's Director of Technical Services Professor Dorington Ogoyi emphasised to the audience that 'labelling is not about safety, labelling is about consumer choice'. It is a confusing statement given the clear dual objectives described within the regulations themselves, but it points to the need to present an outward message of full confidence in the safety protocols of the NBA and represents the way in which, even within the NBA, who are an apparent knowledge broker between pro- and anti-GM groups, uncertainties can be denied and closed down.

At the same conference, a representative from the Consumer Information Network and the Kenya Biodiversity Coalition separately emphasized the importance of protecting consumers' own rights to choose based on their own knowledges and constructions of risk, with reference to Kenya's Bill of Rights, in support of stringent GMO labelling regulations:

> 'I think we should be talking about public concerns, not perceptions, because some of these things… they are real concerns, they are not just perceptions, in terms of addressing public concerns, I think it is a simple thing, transparency and accountability… we have a right to information and that should be made very clear' (Samuel Ochieng, Consumer Information Network, National Biosafety Conference, August 2012)

In such arguments, a case for labels is underpinned not just by recognition of rights, but also of the legitimacy of non-expert knowledges, or those outside of the National Biosafety Authority. The argument made is that public concerns cannot simply be dismissed as perceptions, but rather they must be afforded agency through the permission of choice. This argument is reflected in a point made by Wanjiru Kamau of the Kenya Biodiversity Coalition at the same meeting:

> 'The precautionary principle actually brings in the fact that not everything has to be scientifically proven, if there are socio-economic concerns… that in itself can allow people not to embrace this technology in that area of concern' (Wanjiru Kamau, Kenya Biodiversity Coalition, National Biosafety Conference, August 2012)

The common counter argument to promoting consumer choice advances a more promotional regulatory narrative that focuses on the social benefits of GM technology contextualised within the urgency of the status quo risks (such as food insecurity) that the technology aims to address. This argument is often made in the context of discontent with the basing of Kenyan regulations on those of Europe, which is argued as inappropriate because the urgency for the technology is seen as less acute in Europe. The argument is that consumer choice and opportunities for opposition to the technology should be closed down in order to protect a more urgent citizen need:

> 'Today, critical advances in biotechnology hold the promise of alleviating hunger and malnutrition, so there can be no compromise when some oppose innovation simply because it is new. The government should carefully analyse the cost and the implications of the labelling regulations on food security and the entire economy the immediate victims of the regulation include farmers, millers and consumers' (Paloma Fernandez, Cereal Millers Association, OFAB, June 2012)

> 'In Europe it is a socio-economic issue because they have surplus production. Do they need to increase production? No, so let's put a barrier here ad a barrier here… we cannot take their approach and apply it to our situation because we want to increase productivity' (Florence Wambugu, National Biosafety Conference, August 2012)

However, not only does this contain a number of assumptions about the benefits of the technology and the mechanisms by which production relates to food security and poverty reduction (value-based narrative), but, belying the apparent objectivity of the argument is the reality that it actually plays on a very emotive, and often highly exaggerated, description of the status quo:

> 'The truth is that Kenyan's are very much aware of GM technology and GM products... so it is a myth, and I emphatically emphasize this, it is a myth to actually state that Kenyans are not, or do not embrace..... you will find that 80 percent of Kenyan's are actually willing to consume GM products if that is the only food they can access... therefore labelling is not really informed by the attitudes of the people' (Charles Watoro, reporting on a study of the perception of Kenyans funded by USAID, University of Nairobi, OFAB, May 2012)

The right to consumer choice in such an argument becomes subordinated to the basic human need of food in a very reductionist GMO narrative. As one respondent put it, 'when you have full stomachs, that is when you can start thinking about things that are not necessary' (Anonymous participant, OFAB, May 2012).

As is the case in much of the GM debate, there is a polarisation of perspectives when it comes to the position of consumers and publics in regulation. Whist some argue that the NBA's roles is a paternalistic one and that they are mandated to make decisions on behalf of the public and ensure that they facilitate the social benefits of the technology by making regulations based on objective science, for others safeguarding citizens is about recognising uncertainty and ambiguity within biosafety knowledge, ensuring that technologies are introduced cautiously and that consumers' rights and choices are protected. Unsurprisingly these perspectives often equate to positions that can be broadly categorised as pro- and anti-GM technology and are motivated by personal, political and economic objectives that are very difficult for brokers, such as the NBA, to regulate between. Just as the Biosafety Act was criticised for favouring a technological future, the labelling regulations are criticised for blocking it.

Conclusion

Regulation is largely seen as a barrier by those projects, such as WEMA, wishing to develop and market their technology as a response to the challenges of climate change (often framed as a matter of urgency) and therefore as quickly and cost effectively as possible. Regulatory requirements concerned with labelling and traceability, particularly where these translate into extra costs to be absorbed by the farmer or the consumer, could compromise the viability of the technology for its very target group (smallholder farmers). The inclination is for actors such as WEMA to advance a discourse of regulation that focuses on the social benefits of the technology and the facilitation of research, development and trade, closing down 'risk' to an object that is readily dismissed through scientific evidence (over which these very same actors conveniently hold a monopoly).

A case for deregulation is usually supported through the argument that 'it has been proven there are no risks or safety issues associated with GM crops' (participant at OF2). The language advanced by members of the WEMA regulatory team within regulation debates is that of 'objective science and objective evidence' (BS6) within a 'science-based' system. The predominant assumption, one which underpins almost all discussion of regulation within biotechnology fora and WEMA regulatory documents, is that regulation is (exclusively) about health and (physical) safety. It is an assumption that inevitably places regulation within the realm of a particular body of expertise. That regulatory requirements can be objectively satisfied through uncontested scientific evidence is important for minimizing the barrier that it presents to the progression of biotechnology projects, and allows for the ready dismissal of 'non-scientific objections' (presentation at OF2).

However, dispute over the findings of the Séralini study point to a broader opening up of questions about the authority and certainty of science and the legitimacy of the privileged position that scientific evidence holds within biosafety regulation, and perhaps offers weight to more value-based narratives. It exposes the ambiguities and assumptions of scientific enquiry and, in doing so, offers a real challenge to the way in which the pro-biotech lobby has largely attempted to frame regulatory debate.

The expectation amongst many within the biotechnology research and development community is that the blanket ban on the importation and consumption of GM foods in Kenya will be short term, particularly given the amount invested in the development of agricultural biotechnology in Kenya. However it has been a significant moment in legitimising and publicising health concerns and this will likely stay in the conscience of consumers and farmers alike. It firmly closes the window of negotiation around labelling, for example, because of the revealed uncertainty of scientific knowledge and the clear erosion of the legitimacy of 'expert' knowledges as the lone safeguards against social risk. Furthermore, whilst it may be possible to frame risk and value-based concerns out of the regulatory debate, it is not so easy to frame them out of the conscience of the farmer or the consumer. In cases where the public believes that risks are ignored, or reduced to scientific indicators within regulatory systems, they have fundamental objections to the technology, or where there is a lack of trust in technology developers or regulators then those consumers and farmers will simply feel that they are being forced to internalise the risks themselves (as shown in Chapter Six) and will likely choose instead to not adopt or even protest in response.

The democratisation of biosafety regulation in Kenya represents a test case for the broader governance of agricultural futures in Kenya that this thesis has been more widely concerned with, providing interesting lessons about: the ways that alternative narratives are negotiated and the role of, and approaches to, incomplete knowledge and evidence. These lessons are drawn out and discussed in the following chapter, which looks in more detail at the interconnections between the four case studies presented in the thesis.

Chapter Nine: Negotiating Narratives

Implications for the Governance of Uncertain Agricultural Change

Research Question

'How do different actors narrate the uncertain future of maize agriculture, how can those differences be explained and what are the implications of these differences for the challenges of climate change adaptation in Kenyan smallholder farming?'

This thesis has explored how different actors in different settings narrate the future of maize agriculture. By looking at four case studies in which agricultural change is negotiated and governed, it has revealed the way in which contexts, incomplete knowledge, and interactions with others, shape different narratives of change. Whilst the interdependent nature of narratives and actors has been evident across the case studies, one of the themes of this analysis has been the way in which narratives become insulated through a lack of engagement with alternatives and legitimised through evidence-bases in which incompleteness is not fully acknowledged. In this discussion chapter, attention turns to synthesizing the explanatory findings and addressing the implications aspect of the central research question, and discusses the prospects for, and challenges of, integrating the multiple narratives of these four case studies within a deliberative governance of Kenya's agricultural future. It considers the relationships between different actors and narratives in terms of power, politics, and trust; discusses ways of overcoming structural, communicative, and cognitive barriers to deliberation and scientific citizenship; and identifies and sets out the role of knowledge brokers within this process. One of the central arguments advanced, building on the analysis of the preceding chapters, is that critical reflection on, and open communication of, the nature and incompleteness of knowledge that underpins different narratives of change will be crucial to facilitating a more inclusive and appropriate governance of climate change adaptation in Kenyan maize agriculture.

Actors, Narratives and Incomplete Knowledges

Whilst individuals have been categorised in this research by their social groups, professions and institutions, and these contexts undoubtedly shape, and are reflected, in their knowledges and narratives, these categorisations are somewhat artificial. Individuals often hold multiple stakes, are part of multiple groups, and have personal values, experiences and histories. Hajer's (1995) concept of discourse coalitions (introduced in Chapter Three) provides a useful way of conceptualising the WEMA project which involves national and international public agricultural research institutions, private multinational technology companies, and global philanthropic foundations, all organised around the overarching institutional narrative, described in Chapter Seven, of providing a ‘pro-poor’, ‘climate-change adaptation’, ‘green revolution’ technology. However, evident in each of the four case studies that the research focused on were contested narratives and different degrees of individual buy in or resistance to them.

In the case of climate-crop modelling, for example, whilst complexity logic is somewhat pervasive, there is also the beginning of a backlash to it within the modelling ‘community’ itself, as evident in the favouring of simpler, non-predictive, and participatory modelling approaches. Similarly there are competing framings of GMO risks and benefits that play out within biosafety regulatory debate, and amongst smallholder farmers, there were a multiplicity of knowledges and narratives of change.

The preceding empirical chapters have shown that future climatic and agro-ecological changes in Kenya are differently simulated within divergent climate crop models and in controlled crop breeding stations. Furthermore, uncertainty emerges in local contexts, not just in response to climatic systems, but to linked social, economic, and political systems; often with implications for the appropriateness and adoption of technologies. However, in spite of these knowledge gaps and the multifaceted nature of vulnerability, a narrative of climate change driving a trend towards increasing drought and vulnerability amongst Kenya’s smallholder farmers is particularly persuasive one. It is a narrative that is accepted amongst many (not all) of the individuals and groups involved in this research, including individual smallholder farmers as well as climate-crop modellers and senior management within the WEMA initiative.

By contrast, narratives of response to this climate change problem, particularly relating to technology adoption, GM risks, and potential socio-economic impacts of technologies, are divergent and contested. There is an increasingly dominant, technology-focused framing of a green revolution future within agricultural policy and research in Kenya and in sub Saharan Africa more broadly, but the appropriateness and risks of different technologies and the relative merits of non-technological farm changes are contested by a range of actors at different scales. There is, for example, a direct incompatibility between the narrative of urgency around climate change that is communicated within the WEMA project and a narrative of precaution within biosafety regulation. The nature of this contestation between narratives has been problematized and unpacked within this thesis and it is on the negotiation of these contested narratives of agricultural change in response to climate change that this discussion predominantly focuses.

Particularly when it comes to contestations over perspectives on GM risks, within biosafety debates, certain actors are quick to delegitimise alternative knowledges and narratives by labelling them as 'unscientific'. However, across this thesis it has been shown that the distinction between what is 'scientific' and 'unscientific' or between who is 'expert' and 'non-expert' is misleading, problematic and highly political, not least because all knowledge is a product of some combination of evidence, experience, experiment, values and assumptions and inevitably contains uncertainties, ignorance and ambiguities.

In the cases of climate-crop modelling and crop breeding, fields that are conventionally considered as being 'expert'-led, this research has revealed how these sciences are shaped by institutional protocols, political priorities, subjective methodological choices, and value judgements. A number of assumptions enter into the design of the WEMA maize field trials, the interpretation of survey data about farmer technology adoption, the inclusion of flux adjustments within climate models, the land management input data of crop models, and the methods used for verifying model output projections. But an 'expert' label may be equally problematic when uncritically placed on holders of local knowledge. The research has shown that smallholder farmers and technology regulators make decisions on the basis of their own incomplete knowledges, ranging from assumptions about weather indicators, planting and harvesting dates, and the performance of technologies and varieties, to the interpretation of data from a rat-feeding laboratory experiment and value judgements about the extent to which consumer choice should be protected.

The multifaceted and contextualised nature of decisions about the future means that they inevitably involve the weighing up of multiple risks. For the smallholder farmer, for example, it does not make sense to consider the economic risks of switching to alternatives to maize as their main crop, in isolation of the risks presented by climatic and environmental changes or the risks of being dependent on new suppliers for the inputs for that crop. It is evident how different contributors to biosafety policy place different emphasis on health risks (the main priority of the Ministry of Public Health), trade impacts (a central concern for NEPAD, ASARECA), and implications for consumer choice (of particular interest to KEBS and consumer groups).

In all of the four empirical chapters of this thesis, narratives of agricultural change are linked to the different assumptions, evidences and values that underpin them, and contextualised within social, political, institutional, and historical settings. This tracing of the origins of different narratives gives weight to the assertion made in Chapter Three that rather than being classifiable as scientific and non-scientific, or 'rational' and 'irrational', alternative narratives, in part, reflect the coexistence of multiple rationalities.

A smallholder farmer may, for example, make a rational judgement about the risks of adopting biotechnologies based not on scientific evidence about health risks, but on a wish to avoid new relationships of dependence on seed supply systems or post-harvest processing systems, which history has taught them to distrust. As has been argued by risk studies scholars, so-called 'perceptions' of risk represent the manifestation of incomplete knowledge within specific contexts. As such, risks can become amplified or reduced through histories of experience and social interactions and exchanges. It is clear, for example, that the risk of adopting a new technology for farmers is reduced if they have contact with others that have adopted it successfully. It is similarly evident that GM health risks have been amplified through rumours passed on within insulated social interactions.

A schema of incomplete knowledge developed by Andy Stirling (1999a) has been central to the conceptual and analytical framework of this research. The schema, which is described in Chapter Three, draws a distinction between risk, which reflects relatively unproblematic knowledge about potential outcomes and their probabilities, and uncertainty, ambiguity, and ignorance. It is a schema that is particularly valuable in unpacking knowledge gaps and identifying points at which these are reduced through improved observations and hypothesis testing and where they are filled by assumptions, estimates, and value judgements. However, linguistic problems arise from a more generalised used of the term 'risk' to describe situations in which potential negative outcomes are non-specific, and so not commensurable with probabilities, but are nevertheless feared (i.e. the risk of making a bad decision). In this respect, and in the common use of the term across the actors that participated in this research, risk is not simply distinct from uncertainty, ambiguity and ignorance as a condition of incomplete knowledge, but is a product of them. Biotechnologies represent a risky technology largely because there is uncertainty and ignorance about their long term ecological impacts, health effects, etc., just as climate change represents a risk to rain-fed farming systems because there is uncertainty about the effects of a changing climate on rainfall patterns.

The incompleteness of their own knowledge is often recognised to some extent by actors and many of the individuals involved in this research expressed a willingness to learn from others (and from alternative knowledges). Many farmers expressed a strong desire to receive more information about technologies or weather forecasts as well as training in agricultural techniques through training centres or extension workers. Similarly, a number of climate-crop modellers stressed the value of participatory modelling that could draw on the inputs and insights of actors, such as farmers, which are otherwise distanced from the modelling process, and the development of participatory breeding and varietal selection methods within CIMMYT reflects the value that this institution places on learning from the knowledges of potential adopters.

There are also cases, similarly revealed through this research, in which incompleteness of knowledge is not recognised. This may be because knowledge production is so embedded within institutional protocols that the assumptions and choices on which these protocols are based are rarely given much consideration. This is often the case within scientific institutions in which commonly applied methodological approaches are taken for granted as the objective, or only, method of inquiry. Within climate modelling, for example, the standard approach to verifying model projections is to compare them with the outputs of other models. The result is that confident claims about certainty are often made on the basis of achieving something close to a modelling consensus, with few people looking back at the fundamental assumptions that are common across the models and asking 'what if they are all wrong?'. A similar lack of acknowledgement of knowledge gaps might come about not because they are embedded in institutional protocols, but in social norms. Amongst smallholder farmers, for example, planting and harvesting dates, fertiliser inputs, and post-harvest storage techniques are often assumed to be optimal on the basis of them being a traditional or long-standing approach, without critical consideration of the relative merits of alternative amounts of fertiliser input, the accuracy of local weather indicators, or the appropriateness of having fixed annual planting dates.

In other cases, this denial of incomplete knowledge is more deliberate and serves a particular politically- or economically-motivated end. A denial of uncertainty, ambiguity and uncertainty – 'closing down to risk' – goes hand in hand with arguments against the legitimacy of alternative knowledges. Particularly within the WEMA project, where project partners have an incentive to promote confidence in the technology in the face of opposition and multiple concerns about its appropriateness and safety, grand claims about the benefits of the technology are often made with a false confidence and the safety of the technology is argued to have been objectively proven. In Chapter Seven it is described how the seemingly objective and much heralded claims made by the AATF that WEMA varieties will produce '25 per cent yield gains under moderate drought conditions' is much more political than it is evidence-based. Similarly interpretations of statistics of the growing global adoption of GMOs that are frequently reiterated by ISAAA and AATF appear initially convincing, but are never contextualised within disadoption rates or recognition that whole continents continue to resist GMO technology. It is probably within the biosafety debates that this politics of knowledge is most evident, and Chapter Eight contains multiple examples of arguments about the certainty of evidence with regards to the safety of GMO consumption and, in direct contrast, scientific evidence of health risks. Attempts to frame certain arguments as scientific and, as a consequence, dismiss alternatives as 'unscientific', abound the debate around technology regulation, often creating a stand-off between 'contradictory certainties', as discussed below.

The landscape roughly sketched out above is one in which there are a variety of narratives of agricultural change underpinned by a range of incomplete knowledges, values and political motivations, which themselves are differently reinforced or open to negotiation depending on the dynamics of the social and institutional contexts within which they are shaped. The following section considers further the politics of agricultural change, within this landscape of actors and narratives, and by making reference to some of the empirical findings of the research, with a particular focus on the relationship between WEMA and Kenyan biosafety regulation, it looks critically at the extent to which powerful narratives succeed in closing down to risk.

The Role of Politics and Power

Both within and between the four case studies that are the focus of this research there is evidence of a politics of power acting to determine what narratives of agricultural change dominate. Whilst in many ways a pluralistic picture of power is evident within contestations over the future of agriculture (as discussed below), there are also signs of predictable hierarchies that reflect wealth, resources, and connectedness. It is unsurprising that within WEMA, for example, Monsanto and BMGF's priorities of impact-at-scale, efficiency and agricultural optimisation strongly shape the approach taken to breeding and trialling in spite of, and partially in opposition to, some of the alternative participatory breeding strategies that have been founded within CIMMYT. Power is similarly evident within the making of biosafety regulations and particularly throughout a history of the drafting of the Biosafety Act, during which a well-connected and internationally supported (in the case of PBS capacity building for example) coalition of biotechnology research institutions and representatives from the NCST, were effective in containing the participation of opponents. Concerns raised within public consultations and formalised within the Alternative Biotechnology and Biosafety Bill (e.g. requirements for socio-economic impact assessment) were effectively framed out of the Act. This power to frame agendas exists in an even more subtle way in the ‘public sensitization’ efforts that organisations such as ISAAA are engaged in, which strongly promote a particular framing of biotechnologies as social goods to be promoted through facilitative regulation.

Particularly within the biosafety debate, which is highly politicised, one of the most common manifestations of power is in the making of claims over the ownership of objective knowledge; claims of taking an evidence-based stance in contrast to irrational opposition. ‘Rationality’ is adopted (on both sides) as a mask that attempts to hide underlying power plays.

However, even in recognising that power manifests itself in multiple and subtle ways, an analysis of Kenyan biosafety debate that reduces it solely to one of power is unsatisfactory. The case of labelling regulations and the controversy over the 2012 ban on importation and consumption of GMO foods, justified by the Ministry of Public Health through a principle of precaution, points to a broader opening up of questions about the authority of science and the legitimacy of the privileged position that scientific evidence holds within biosafety regulation. Decisions made in both cases, contrast with the experience of the Biosafety Act and indicate that there is not an obvious and predictable pattern to whose narratives and framings win and whose lose within these debates.

Although certain concerns may be framed out of the regulatory debate, they may persist within the conscience of the farmer or the consumer, who exercise their own agency when it comes to making decisions about adoption and consumption. Where members of the public have fundamental objections to the technology, or where there is a lack of trust in technology developers or regulators, then as consumers and farmers they may choose not to adopt or even protest in response, and these decisions, of course have implications for the ultimate success of the WEMA project, for example. Similarly, if farmers (who would be key ‘operators’ in the traceability of GMOs across the production chain) object to the imposition of strict regulations around their use of the technology, particularly with regards to traceability regulations, they may exercise their agency through non-conformance, a decision which, given the incompatibilities of smallholder farming systems with monitoring and enforcement of regulations, they have a good degree of autonomy to make.

The implication for WEMA, for example, is that for AATF and ISAAA simply to promote its narrative through public sensitization exercises or political lobbying, in spite, or ignorant, of the alternative values held by the public and their distrust of institutions or fundamental objections to the technology, could be ultimately damaging to the viability of the project. Technology developers cannot presume just to present 'evidence' to a regulatory debate, particularly in relation to something so explicitly uncertain and ambiguous as the urgency of a technological response to climate change, and expect to convince those concerned with social implications or sceptical of the motivations and legitimacy of the 'evidence' providers to simply accept the policy narrative that is being advanced.

Across the four case studies, there are examples of powerful actors constructing narratives of change in agriculture, closing down uncertainties, ambiguities, and ignorance to risk, and excluding alternatives. However the case of the barrier that labelling regulations and the Ministry of Public Health's ban on GM foods represents to the internationally supported and politically powerful WEMA project is an example of how contestations over the future of agriculture are not simply captured and controlled by elites; giving hope that there may be other (potentially more just) mechanisms at work. The following section, then, looks beyond power dynamics to the mechanisms of, and potential for, governance of agricultural climate change adaptation in Kenya that is based on persuasion, deliberation and social learning across knowledges.

Social Learning and the Governance of Kenya's Agricultural Adaptation

Black (1998, 2002) recognises that it is in the negotiations of the meaning attached to the concepts of public interest and risk that governance happens (Scott 2004). Negotiations take place not just within formal political debate, but in multiple locations, societies and institutions, and amongst a multiplicity of actors. Effective governance requires integration at multiple scales – in the design of projects, the establishment of institutional protocols and priorities, the choices of farmers, the regulation of risk, and others. The theoretical benefits of achieving this kind of deliberative governance are two-fold, relating to both the quality of decision-making and the acceptability and support for decisions. Head (2010) suggests that the success of evidence-based policy making depends in part on the interaction and mutual understanding between policy professionals, researchers and decision-makers:

> 'Researchers need to work on important issues, ask the right questions, and provide relevant findings in a well written and accessible way. Additionally, where possible, the implications of the research for policy and practice might be noted. On the other side of the ledger, policy managers need to become more aware of the value of relevant research, become more adept at accessing and using such research, understand both the strengths and limitations of the evidence base, and know how to balance the competing perspectives of research, politics and management' (p. 82)

Given the interconnected nature of the case studies and the fundamental dependencies of narratives within different settings and at different scales, it is clear that in order to plan appropriate and effective narratives of change in response to an uncertain climatic, as well as social, economic and political, future; policy makers, crop scientists, climate modellers and farmers alike need to contribute to the negotiation of narratives of agricultural change. There is a need for collective learning in which actors reflect critically on their own incomplete knowledge and show a willingness to adjust their own narratives in response to the knowledges and values of others. The following discussion considers these benefits in some of the governance contexts that have been studied in this research.

Modelling of future maize productivity can produce policy relevant information that can make important contributions to improving preparedness and the quality of decisions about narratives of change, but its utility is dependent on the ability of modellers to identify, trace and communicate incompleteness within this knowledge (this information is just as relevant in policy and action as the outputs of the models). One area in which the participation of alternative knowledges would be most appropriate is in the very framing of the modelling endeavour; the establishment of policy problems that models might be directly designed around responding to (e.g. modelling rainy season onset dates or the impacts of particularly changes in agricultural practice on maize yield).

Smallholder farmers can benefit from increased engagement with technology developers and climate forecasters in order to make more informed decisions about a future about which they themselves have an incomplete knowledge. This is a point that has been argued by Todd Crane (Crane, 2010), for example, in relation to the use of climate impact and adaptation models within farmer decision making. Engagements may provide information about technologies that were previously unknown, such as was the case with demonstrations at agricultural shows in Nandi district of triple-ply post-harvest storage bags, but may also provide more evidence of success of technologies, and even reduce scepticism or build trust between farmers and information providers or supply system actors (the themes of trust and accountability are discussed in more detail below).

The seed technologies developed through crop breeding represent a valuable tool for improving the resilience of agriculture, but their utility and appropriateness is inextricably linked to the preferences and concerns of the technology adopters (farmers), which are in turn shaped by their experiences and social interactions, and the nature of uncertain agro-ecological, social, economic and political change. These are highly contextualised. The broader the scope of breeding (e.g. the larger the mega environments at which crops are targeted), the more problematic are assumptions about adoption and solution. The participation of alternative knowledges may challenge the assumptions that underpin the pre-defined crop performance indicators (e.g. anthesis date, senescence of leaves, etc.) of crop breeders. The earlier that this deliberation takes place, however, the more scope there is to shape projects, even challenging assumptions about the appropriateness of targeting drought-tolerance, concentrating on maize, and utilising GM technology, for example. To analyse critically the broad endeavour of breeding drought tolerant maize it is necessary not simply to look for evidence of success that comes in the form of yield improvements on trial sites, or even technology adoption rates (as is common practice within technology development projects), but to look at whose needs are being served by the technology, how it compares to other agricultural adaptations and technologies, and what impact it has on these alternatives. This is an evaluation that must be multi-sited and draw on the knowledges, experiences, evidences and values of those with a stake in the future of maize agriculture.

The regulation of technologies equally benefits from citizen participation in the identification and evaluation of the social risks and benefits of technologies, particularly where these relate to socio-economics, and the determination of most appropriate ways to safeguard citizen's needs, rights, and interests. Participation within debates about national policy on biotechnology and regulatory requirements for safeguarding citizens offers a means of both designing regulation that responds to citizen interests and needs and is more practicable within the realities of farming systems in particular, but also of raising awareness about and increasing the transparency of technology regulation. Discussions with smallholder farmers (presented in Chapter Six) suggest that levels of awareness about regulatory mechanisms around biotechnologies are low and this undoubtedly contributes to an increased perception of risk around the technology. A more inclusive policy debate around regulation is likely to increase trust in regulating bodies and may even improve willingness to adopt technologies. There is good reason for those from the pro-biotech lobby to encourage the voicing of, and discussion around, public concerns about the technology and its regulation and even accepting stringent safeguards, where such measures result in a more engaged, informed and invested public.

Reflecting on Incomplete Knowledge

Whilst the general prescription of increasing the participation of alternative knowledges and social learning is undoubtedly of broad value across the case studies, it is not necessarily broadly practical or efficient. Certain knowledge gaps simply necessitate the increased endeavour of individuals (scientists or farmers for example), whilst others may be served by better communication to uninformed groups or through the collaboration of a very specific group of actors. Throughout this thesis, Andy Stirling's schema of incomplete knowledge has been adopted in recognising the difference between uncertainties, ambiguities, and ignorance, and this offers a useful means of achieving an epistemological realist unpacking and analysis of the legitimacy of knowledge claims (van Zwanenberg and Millstone, 2000) and a schema for identifying those gaps in knowledge in which deliberation and learning would be most appropriate and better targeting approaches to knowledge building across and within groups of knowledge holders. Table 9 lists some examples of areas of ignorance, uncertainty, and ambiguity across the case studies and details related prescriptions of strategies for building knowledge.

Table 9 Examples of ignorance, uncertainty, and ambiguity from across the thesis with relevant strategies for addressing incomplete knowledge

	Examples from this research	Strategies for addressing incomplete knowledge	Relevant Stakeholder
Ignorance	• Lack of understanding of the relationship between ENSO events and the Indian Ocean Dipole amongst climate scientists	• Increased observation and data collection	Climate scientist
	• Lack of awareness of and knowledge about alternatives to maize amongst smallholder farmers	• Increased attendance at agricultural shows and participation in agricultural extension	Smallholder farmer
	• Lack of understanding of the socio-economic impacts of GM crop technologies within WEMA project	• Increased socio-economic impact assessment	CIMMYT socio-economist
	• Lack of awareness of the risks and benefits of GMOs amongst farmers, consumers, and policy-makers	• Increased public awareness raising and communication	Science communicator
Uncertainty	• Divergent and unclear evidence about future trends in water availability	• Combine information from a variety of models of differing scales and of differing complexity (with critical consideration of the limitations of each)	Network of climate modellers
	• Divergent and unclear evidence about local weather patterns (onset, duration, quantity, and cessation of rains)	• Combine information from forecasts with local indicators, and experiences of trends to make judgement (with critical consideration of the limitations of each)	Network of local climate knowledge
	• Unclear evidence about the performance of crop technology under farm conditions	• Combine information from trialling under a range of conditions (including on-farm) (with critical consideration of the limitations of each)	Network of crop breeders and testers
	• Divergent and unclear evidence about the safety of consuming GM foods	• Combine information from a range of toxicity/allergenicity studies of different methods, with critical evaluative of the robustness of method (with critical consideration of the limitations of each)	Network of biosafety scientists
Ambiguity	• Different perspectives on how model inputs (e.g. land management) should be parameterized	• Negotiation (particularly drawing on relevant local knowledge) of scenarios, key parameters and on-ground realities	Modellers; smallholder farmers; technology developers
	• Different perspectives on priority traits for maize	• Negotiation of priority traits for maize and appropriate evaluations of these traits	Modellers; smallholder farmers; technology developers
	• Different perspectives on the value and appropriateness of alternative breeding strategies	• Negotiation of breeding priorities and the cost/benefits of alternative strategies	Smallholder farmers; technology developers; lobbyists; technology regulators
	• Different perspectives on the roles and responsibilities of regulators (e.g. in relation to socio-economic impacts)	• Negotiation amongst policy sectors and stakeholders to identify risks and agree responsibilities	Smallholder farmers; technology developers; lobbyists; technology regulators

Areas of ignorance, around which both potential outcomes and their probabilities are unknown, across the cases, represent a lack of understanding or information about an issue or process. This may refer to the ignorance of an individual in relation to something that is known about elsewhere, or ignorance within whole fields of research in relation to a problem about which the answer is yet to be discovered. In both cases however, building knowledge similarly depends on gathering information through a relatively individual endeavour (i.e. research programmes within (as opposed to across) institutions). Ignorance about the socio-economic impacts of the WEMA technology within CIMMYT, for example, undoubtedly warrants a greater endeavour within its socio-economics research programme to collect data pertaining to the contextualised socio-cultural risks of GM technology adoption for smallholder farmers.

Uncertainty, which is defined as a condition in which potential outcomes are confidently known, but probabilities are not, across the case studies, emerges in situations where there is divergent or unclear information about an issue or situation; divergent climate model projections, for example. In such situations, knowledge gaps may be reduced by drawing on knowledge that exists within defined communities of expertise or beyond them, by combining knowledge that contributes to a common problem. The unpredictability of the local onset and cessation of rains is a situation in which combining different sources of knowledge, from weather forecasts to local and traditional indicators of rainfall (as discussed in Chapter Six), can help farmers to reduce the uncertainty associated with short-term rainfall patterns. Although, as Chapter Five discussed, this combining of knowledges is not simply a matter of averaging out divergent projections in order to reveal the most likely outcome.

Areas of ambiguity, in which it is the identification of outcomes themselves that is contested (or at least contestable), across the case studies, represent the greatest scope for narrative negotiation. Typically these are issues over which fundamentally different perspectives exist and where alternative knowledges might speak to alternative conceptualisations of the question or problem. This is the case, for example, with regards to different framings of GM technologies and the roles of regulation or even different perspectives on how models should be designed (e.g. determining policy problems, appropriate scenarios and alternative land management options to be modelled). In such situations it is important that negotiation of knowledges and a process of social learning take place across actors and across scales, requiring farmers, policy-makers, crop breeders and climate scientists to engage with and learn from each other.

Achieving Good Governance: Challenges and Opportunities

There are a number of opportunities for these negotiations to take place, including participatory modelling, farmer meetings, agricultural shows, participatory crop breeding, agricultural extension service provision, on-farm field trials, open policy fora, stakeholder workshops, and public debates, as well as specifically designed projects, such as those of the Humanitarian Futures Programme and the Climate Science Research Partnership, and many of these have been represented in the sites that this research has taken place in. However, as has been shown across the chapters, interactions within these locations are often dictated by power and politics or are restricted by barriers:

- Complex climate models are difficult for 'non-experts' to engage with and projections are often presented in reductionist ways that narrow space for the negotiation of their legitimacy.
- Smallholder farmers interact with untrustworthy actors and inaccurate information with consequences for their willingness to engage.
- The motivations of WEMA partners have acted to limited space for the negotiation of the priorities, scale and design of technology development.
- Consultation around the drafting of the Biosafety Act was closed down by powerful interest groups.

There have also been cases in which these barriers have acted to reinforce the kinds of contradictory certainties that make governance so difficult. The regulation of biotechnologies is perhaps the clearest case of this, where pro- and anti-GM perspectives have become so entrenched, partly because meaningful deliberation over their respective narratives, as opposed to one-sided efforts at sensitization, rarely happens.

Black (1998) distinguishes between: 'structural' barriers, which relate to an absence of infrastructure for communication and deliberation to happen through; 'communication' barriers, which relate to different people talking different languages not just in terms of national and local languages but also in relation to the inaccessibility of institutional or discipline-specific terminologies and styles of information presentation; and 'cognitive' barriers, which is the label that she gives to the challenge of people bringing different conceptualisations and framings of the issue or beginning from different value-bases and experiential groundings that are often implicit and, in some respects, non-negotiable. In addition to these, throughout the empirical chapters of this thesis, the absence of trust between actors has emerged as a fourth significant barrier to good governance. Of course this is closely interconnected with other barriers and may be the result of a history of miscommunication and exclusion, but distrust and scepticism may continue to have a negative impact on the willingness of individuals to engage with, and respond to, alternative knowledges.

In overcoming these challenges, the design and structure of fora and the role played by knowledge brokers in facilitating dialogue and learning will be crucial, as will the commitment of participants to reflecting on, and openly communicating, incompleteness within their own knowledge bases. In this section, some of the specific challenges of governance relating to each of the four case studies are described and ways of overcoming these challenges, with a particularly emphasis on identifying and outlining a role for knowledge brokers, are discussed.

Climate and Crop Modelling

A combination of communicative and cognitive barriers to participation in climate-crop modelling comes as a direct result of the complexity logic convention in modelling. As argued in Chapter Five, the assumptions involved in modelling multiply in number and divide in size as models become more complex. Essentially complex models act to fractionate the knowledge gap. For example, the task of parameterizing terrestrial carbon cycling in a simpler model, and making the assumptions involved in it, may, in more complex models, become separated into tasks of parameterizing soil carbon storage capacities, sequestration rates, numerous biogeochemical feedbacks, etc. (Randall et al., 2007). Fractionating incomplete knowledge through increasing model complexity has important implications for the utility of its outputs, not least that, as is the case with the AOGCMs used by the IPCC, knowledge production, incomplete knowledge, and assumptions become widely dispersed across a large international and interdisciplinary set of experts, making modelling assumptions very difficult to trace, even by those involved in the modelling process (Shackley et al., 1998, Lahsen, 2005). Lahsen (2005) points out that the complexity and resultant dislocated nature of knowledge bases makes the endeavour to involve modellers themselves in communicating uncertainty, and facilitating co production of knowledge, incredibly difficult:

> 'The 'certainty trough' (Mackenzie, 1990) describes the level of certainty attached to particular techno-scientific constructions as distance increases from the site of knowledge production, and proposes that producers of a given technology and its products are the best judges of their accuracy. Processes and dynamics associated with GCM modelling challenge the simplicity of the certainty trough diagram, mainly because of the difficulties of distinguishing between knowledge producers and users and because GCMs involve multiple sites of production' (Lahsen, 2005: 895)

In complex climate models, the technology production is highly dispersed across academic disciplines and geographic continents – from meteorological observation stations to fluid laboratories and from computer programmers to social scientists – and is for the most part disconnected. The result is that even the experts find themselves detached (at some distance) from the production of the model, and the detailed understanding of incomplete knowledge in the process is not held by, or accessible to, any one scientists, research group or even academic discipline. This creates particular problems for communicating across the certainty trough, although one might hear, loud and clear, the vociferously critical voices of those distanced from the models who do not trust their projections, as well as those that have a reasonable understanding of the science and defend the accuracy and reliability of the models, there are very few who can stand at the other side of the trough and identify uncertainty with a detailed knowledge of the full, intricate, and incomprehensibly complex, production climate model projection. Problematically, this complexity and resulting dislocated knowledge base leaves the door open for politically motivated, biased and ignorant claims about uncertainty and offers a source of legitimacy that is increasingly captured by climate change deniers.

Karl Popper's (1982) argument that complex theories 'may become untestable' is supported by the difficulties of tracing uncertainties and assumptions within complex climate models. This has implications for the transparency and accountability of climate model outputs, making challenges to their accuracy difficult both to make and defend against (Bulkeley, 2001). It also means that, within complex models, achieving the meaningful participation of 'non-expert' knowledges is highly problematic. Inputs are restricted to individual model segments that are necessarily pre-framed within the mechanisms of the overall model and so it may only be in the very early stages of model conceptualisation that deliberation has the potential to frame, and even have an effect on the interpretation of, model outputs. The reality for Kenya, and for sub-Saharan Africa more generally, is that this conceptualisation and the bulk of the modelling process takes place in European and North American institutions, often linked to regional CGIAR centres, for example, and, as such there are a number of intermediaries (such as through the Climate Science Research Partnership) that both link farmer knowledges and processes to these modelling endeavours and, essentially separate them from direct participation in it. It is in these channels of knowledge exchange that appropriate and effective infrastructures are important for facilitating participation.

Participatory models offer a forum for achieving the integration of knowledges within the assumptions and methodological choices of the modelling process itself and a useful approach for better aligning projection assumptions with policy utility in the projection outputs. It is an approach that focuses on the integration of local and scientific knowledge for describing the dynamics and key parameters of a system within a useable model. In the participatory modelling process, stakeholders play an important role in identifying key system dynamics and defining the interrelationships between them. Such models are capable, for example, of better linking physical representations of climate and crop innovation with cultural, political, social and economic parameters of the agro-climatic system, and facilitate a prior discussion of policy problems around which models can be designed.

The ability of models to capture dynamics and complexity, mean that they offer advantageous ways of systematically structuring stakeholder knowledge for policy analysis. By integrating stakeholder conceptualisations of system structure and function with process-based models, it becomes possible to identify feedback loops and other non-linear or emergent behaviour of complex systems that would be difficult for some stakeholders (particularly smallholder farmers) to anticipate otherwise. It is also possible to explore a range of futures in far greater, plausible detail than would usually be possible using stakeholder inputs alone.

Participatory modelling approaches vary from complex formula-driven system descriptions for which participants may be asked to generate or provide input data (e.g. Anselme et al., 2010), to much simpler qualitative description, that permit stakeholder negotiation over the design of system components and parameters (e.g. Huber-Sannwald et al., 2006). The application in both cases, is usually as qualitative heuristics to aid decision-making; in the development and illustration of scenarios (Prell et al., 2007, Whitfield and Reed, 2011), or testing the robustness of co-constructed adaptation strategies against a range of potential futures. Although current investments largely contribute towards large-scale complex modelling endeavours (and there continue to be calls for greater investment, e.g. through the World Modelling Summit for Climate Prediction (Dessai et al., 2009)), such strategies are not necessarily best suited to addressing policy questions or facilitating participatory input. As such re-allocations of budgets and specific investments that focus on the development of more accessible non-predictive models designed around particular policy questions would help to shift the balance of the global climate modelling endeavour and open up uncertainties to the input of alternative knowledges and facilitate the negotiation of ambiguities.

Because Kenyan smallholder farmers are disconnected from modelling processes that predominantly take place in international institutions, there will be an important role for intermediary organisations that can essentially translate inputs in both directions and provide forums for knowledge exchange. The Humanitarian Futures Programme, the UK Meteorological

Office's Climate Science Research Partnership and, to some extent, the CCAFS group of the CGIAR are endeavouring to provide this intermediary service, but they are subject to capacity restrictions. A greater commitment towards investment in these projects and increased effort towards building networks of knowledge partnerships within CCAFS, the Met Office, and others, would go a long way towards improving the policy utility of the wealth of knowledge that climate modelling institutions hold.

Promoting a more thorough reflection on, and communication of, incomplete knowledge within climate-crop modelling will require the engraining of this ethos within institutional protocols, but will also require a coordination effort across a vast modelling community. To some extent this already takes place, and the IPCC reports have developed a framework for reflecting levels of certainty and consensus amongst modelling experts, but this is largely aggregative and semi-quantitative, such that final reports offer a misleading closing down of incomplete knowledge.

Smallholder Farming

Chapter Six describes a recent history of internalising decision making on the part of smallholder farmers that reflects a distrust of external actors, projects, policies, and information due to the experience of negative outcomes from interactions with them. Distrust may be both a barrier to good communication and a product of a lack of communication, and the two can be mutually reinforcing. If a farmer has been stung by adopting an ultimately failing technology or farming technique under a false impression about its certain 'silver-bullet' benefits, then they are less inclined to seek or trust information from external actors. A lack of trust, in turn, makes it more problematic for an external intervener to be open about the uncertainties of their intervention.

Importantly, the challenge in such cases is not simply to persuade farmers of the benefits or validity of a particular narrative, as is often assumed within the public sensitization efforts of ISAAA and the AATF, because the risks and benefits do not necessarily exist solely within the narrative, but also within the relationships between actors, and because the adaptation priorities of farmers may be very different from those assumed within it. Much of the risk associated with adopting biotechnologies for the farmer, for example, may be that it forces them to invest in and become dependent on particular seed supply systems, which they have known to be corrupt, or that it brings them the jurisdiction of new regulations that they are wary of. As such, whilst trust can be a significant barrier to deliberative governance, building trust through deliberation is essential for the achievement of viable narratives. Particularly for a project such as WEMA, the success of which will be ultimately dependent on farmer and consumer trust in both the WEMA organisations and the technology itself.

One of the most successful information providers and knowledge brokers within the sites of this research was a non-governmental agricultural training centre (in Nandi district), which provided community extension services (in some respects filling a gap left by the decline in governmental agricultural extension). High levels of trust in the information and advice offered through the centre were directly related to the permanent presence of the centre within the community and the way that it involves farmers in establishing and evaluating trials of new technologies and techniques on farms, such that knowledge and evaluations of changes are experiential and co-produced. There are lessons to be learnt from this model of operation in terms of how government services, as well as technology developers, operate within smallholder farming systems, particularly in terms of facilitating long term participation in experimentation with, and evaluation of, change.

Crop Breeding

There is a stark contrast between the WEMA confined field trials and CIMMYT's participatory varietal selection exercises of the AMS and other crop breeding programmes, in which emphasis is placed on the transparency of the process and the opportunity for the basis of evaluation to be opened up, at an early stage, to a whole range of farmer-defined and locally appropriate indicators of efficacy. A discussion of the comparison of AMS with current CIMMYT breeding with a CIMMYT social scientist suggested that crop breeding has become targeted at much more aggregated environments than was possible during AMS (DW7) and there is little space for social and economic geographies, both within and beyond the boundaries of these zones to be reflected in the results of crop trialling (geographies that might otherwise be reflected in a more locally targeted and participatory breeding process). Opportunities for farmer input are also restricted to a late stage process, more for the purpose of verification than being an opportunity to shape the trajectory of technology development. Genetically modified crops represent a significant departure from conventional breeding, particularly when viewed from a societal perspective. Tight controls over the testing of GM crops, combined with the patent and intellectual property protections that are necessary to both protect the commercial interests of private partners and maintain traceable production systems, inevitably come at the expense of societal ownership of, and social learning around, the technology.

Across the empirical chapters of this thesis it has been shown that risks and opportunities associated with future uncertainty are constructed in local contexts and are highly contextualised within social, political, institutional and economic settings. What emerges as a result is a complicated and high-resolution geography of risk, with localised implications for the appropriateness of technologies.

Critical engagement with contextualised and locally-defined risks and preferences happens to an extent through CIMMYT's DTMA work, which has incorporated participatory breeding and involved evaluations of seed supply systems, but remains predominantly limited to attempts to remove barriers within technology supply chains. WEMA represents a significant departure because it deals with genetically modified crops, and so the project partners, and CIMMYT in particular, must be careful that the impact-at-scale priorities and focus on producing optimal technologies of its private partners (and philanthropic donors) do not force the assuming away of GMO risks that are constructed in local and social contexts.

In both DTMA and WEMA, these findings suggest that there is a need for mechanisms of scaling down from overarching breeding programmes, and particularly engaging with some of the historical and social barriers that exist at more local scales. In both initiatives it is necessary that the trade-offs between streamlined technology delivery and engaging with contextualised farmer knowledges and needs in shaping the breeding programme is carefully considered.

As in the case of participatory breeding, ensuring these mechanisms of scaling down are sustained may be a case of establishing this as a priority within CIMMYT protocols on entering into partnerships that might push a more universalised approach. There is also a need for more investment in this scaling down process and particularly in terms of building capacity with NARS, such as KARI, to implement localised farmer field trials and for the information that is generated from these trials to feedback into the breeding programmes, not just of KARI but of private seed companies and, crucially of CIMMYT itself, such that programmes are not restricted to being framed by the assumptions that are manifest in the initial CIMMYT germplasm, but have the agency to affect this framing, and the broader breeding programme. This upstream participation would provide a means too of deliberating over the relative merits of different breeding and trialling techniques and strategies.

In the case of projects such as WEMA that depend on the buy-in of actors (e.g. farmers and regulators) to their narrative, the acknowledgement of incomplete knowledge is both essential and dangerous. The need for project partners to prove the worth of the technology to its doubters inevitably leads them to overstate not only the benefits of the technology, but the level of confidence that they have in it, but presenting an impenetrable narrative and bombarding the public with messages of 'sensitization' is unlikely to sufficiently build public trust in the narratives, its motivations and the project partners themselves.

Technology Regulation

In relation to Kenyan biosafety regulation, in particular, this research has shown a need for an opening up to multiple understanding of the risks associated with biotechnologies and particularly the need for clearer obligations and guidelines for addressing non-health-related GMO risks. Responsibilities and protocols for conducting socio-economic impact assessments associated with GM technologies particularly need to be clarified, whether this is to come at the stage of confined-field trial applications or environmental release applications. To avoid the dismissal of 'unscientific risks' as illegitimate barriers, whether for political reasons or because of entrenched perspectives, there is a role to be played by independent and participatory research into these social and economic impacts and these ought to look beyond yield gains, success stories, and assumptions about adoption, and instead provide systematic and localised analyses of GM pathways in relation to the livelihood and land management strategies of farmers, conventional breeding, and other pathways of agricultural change, and consider the potential for these pathways to be closed down or opened up as a consequence of GM technology development and release. It is on the NBA that the responsibility for defining these responsibilities, and demanding that biosafety applications make reference to these socio-economic impact assessments, falls.

Similarly, and in addition to the consideration of socio-economic impacts, the integration of multiple constructions of risk could be achieved through a more rigorous and accessible system of public consultation that takes place around NBA applications. The NBA draws heavily on expertise within a community of in-country genetics scholars, both in terms of the drawing up of biosafety regulations and in making assessments about the biosafety applications. As described in Chapter Eight, this is quite a close-knit community within Nairobi and there are commonalities in knowledge systems and values of this group. There is currently very little representation of farmers and consumers within NBA application assessment panels and input depends on being able to access approved applications online and make formal objections within a short 'public consultation' window. The NBA's Annual Biosafety Conference represents a forum for potentially engaging publics and alternative knowledges, not necessarily in the consideration of specific applications, but in the shaping of general principles of assessment and biosafety, and the NBA must work hard to ensure that it becomes an effective forum for this kind of engagement.

Central to achieving this engagement will be addressing the cognitive and communicative barriers that currently act to exclude certain knowledges and actors, particularly on the grounds of the being 'unscientific'. Incorporating socio-economic impacts more centrally within the remit of technology regulation will be an important means of opening up discussion around regulation to alternative framings of, and concerns about, the technology. Finding non-technical ways of communicating the evidence bases and protocols of biosafety, such that they are intelligible to a broader audience is an important, and acknowledged, responsibility of the NBA as the key knowledge broker within biosafety regulation.

Across all of these four case studies, opening up narratives to negotiation involves critical reflection on the incompleteness of knowledge in order to recognise the benefits of, and opportunities for, social learning through engagement with alternatives. Deconstructing (institutionalised and socially-embedded) knowledge generating processes to reveal ignorance, uncertainties, and ambiguities represents a productive way of critically reflecting on the nature of incomplete knowledge and identifying in which locations, and between which actors, negotiations across knowledges would be most achievable and useful, and hence has a valuable role to play in the advancement of good governance. As such, both the findings of this research, regarding the discovery of contextually-embedded knowledge gaps across multiple sites and the approach of the research to exposing and analysing these gaps, are of potential relevance across a variety of governance issues, in which multiple voices draw on alternative knowledges. The scope of issues in which the research has applications and implications go beyond the agricultural sector, and have relevance to the design and regulation of technologies, public health planning, natural resource management, urban planning, natural hazards, and many more.

Independent studies, of which this research is one example, offer useful insight into the existence and nature of knowledge gaps. By taking a multi-sited approach and by focusing on the ways in which knowledge is shaped through contexts, interactions, histories and experiences this research offers a number of insights into the way that different, and even contradictory, ideas and framings of climate change adaptation emerge amongst different individual groups, and exposes the ignorance, ambiguities and uncertainties that underpin them. This research represents not only an argument about the need for a more deliberative negotiation of narratives around the future of Kenyan agriculture but it also offers an initial contribution to the necessary unpacking of knowledges and narratives of the future that such governance must entail. This combination of analytical realism and social constructivist scholarship on agricultural climate change adaptation can provide a useful basis on which to build knowledge exchanges and collaborative and interdisciplinary adaptation initiatives.

Avenues for Further Research

A logical next step within this research would be to create opportunities, and evaluate the effectiveness of different fora, for the renegotiation of knowledges and narratives on the basis of multiple actors reflecting on the nature of their own incomplete knowledge. It was beyond the scope of this research to be able to physically connect the multiple sites of the research and to feedback the analysis of knowledge to see how well it might practically facilitate deliberations. In Table 2 (in Chapter 3) a variety of methods and instruments of risk governance are listed, and a systematic trialling and evaluation of these for achieving deliberative governance of agricultural change in this context, would represent a useful extension of the research. Here too there is a need for the development of self-reflection tools that allow for the analysis of knowledge gaps to be conducted by participants themselves, such that the success of renegotiating knowledge does not depend on independent research, but can be self-sustaining and continual. Such tools would necessarily be tailored to context and draw on sociological, psychological and communications research.

As mentioned above, there is scope for the application of the research framework and approach – combining its analytical framework and ethnographic approach to unpacking, analysing and explaining knowledge gaps and narratives across multiple sites – to a broad variety of governance issues and sectors. Through its broader application it is likely that this novel approach would be enhanced by the development of increasingly sophisticated and insightful frameworks and tools.

Conclusion

The discussion presented above reflects on the findings from the four case studies presented in this research and draws lessons from a lateral look across their commonalities. The thesis as a whole engages with a variety of narratives of agricultural change, which are shaped in social and institutional settings and underpinned by combinations of evidence, values, assumptions, and political motivations. These narratives are contested in multiple sites and by a variety of actors and, although the resolution of these contestations often fall along familiar lines of power and elite capture, there are also examples in which alternative perspectives find agency. The challenge of good governance of agricultural change, it is argued, is to integrate multiple perspectives and to achieve social learning through a negotiation of narratives that is not dominated by elite capture and framing, but is open to multiple alternatives.

This research has adopted participatory and ethnographic research approaches across a number of locations and with a variety of actors with a stake in climate change adaptation in smallholder maize farming and this has been combined with an analytical framework that draws on Stirling's schema of incomplete knowledge. The use of this framework to systematically analyse the nature and origins of knowledge claims has been demonstrated across the diverse sites of this research including areas where constructivist analyses are rare, such as in the unpacking of climate-crop science and unpacking of the local knowledge of farmers. Furthermore, the research presented demonstrates how such an approach can be used for a realist analysis of the construction of knowledge and as a means to identifying knowledge gaps most appropriate for negotiation. The other important element of the analysis was of the social context within which knowledges are framed, and this has begun to reveal the value of ethnographic tools for critical reflection on the process of risk construction – again important for making space for the renegotiation of knowledge. Methodologically, the approach of combining ethnographic study with participatory research made for a flexible approach that was again applicable across diverse sites and in studying a diverse range of knowledge generating processes. By revealing disconnections as well as interconnections between the varied subjects of the research, the findings speak to the debate about whether ethnography can truly be 'multi-sited' and support the idea that distinct sites are not simply the misleading constructs of the researcher, but that disconnections are real and experienced.

By taking this multi-sited approach and by focusing on the ways in which knowledge is shaped through contexts, interactions, histories and experiences it offers a number of insights, not only into the way that different, and even contradictory, narratives of climate change adaptation emerge amongst different individual groups, but also into how these ideas are shaped in response (and even opposition) to each other. This has important implications for addressing the structural, communicative and cognitive challenges of governing risks, uncertainties, ambiguities and ignorance.

Within participatory research and governance – which may be in the form of participatory modelling, breeding, scenarios, etc. – understanding the origins of values, norms, cultures, concerns and constructions of risk (of scientists and non-scientists alike) is important for achieving deliberation over, or negotiation of, perspectives. Multi-sited and institutional ethnographic research, and the application of an analytical framework based on a schema of incomplete knowledge, which has been shown in this research to be applicable in the identification and tracing of incomplete knowledge, can offer an insightful basis for the improvement of adaptation and planning policy. Studies such as this that unpack multiple knowledges and set about describing points of connection and disconnection between them are valuable in providing a basis from which to design and implement knowledge exchanges.

Given the focus on critical reflection and the origins of incomplete knowledge and assumptions, it is of course important to recognise the assumptions, values and biases within the research itself. I take it as a reassuring sign that my own expectations and narrative have changed as a result of engaging with and learning from people in all four of the case studies. Certainly the passions and motivations of contributing towards poverty reduction of those involved in crop breeding and even in higher level management of the WEMA project challenged and changed my preconceptions that it would represent insular technocracy and the experimental and systematic evaluations and decision-making of smallholder farmers revealed a good deal more rationality and much less ignorance about the science of crop genetics and agricultural inputs than I was expecting. Similarly, within climate and crop modelling, the recognition of knowledge gaps and calls for a more integrated and participatory approach to modelling were somewhat at odds with some of my preconceived ideas about objectivism within a 'scientific community', and the finding that biosafety debates weren't completely dominated by conventionally powerful actors was also unexpected. Some of these ideas, of course have been supported by the research, but to claim that they are completely evidence-based would be to deny that they also reflect my own assumptions and values.

Just as has been the case in my own experience of researching and writing this thesis, I would argue, in very broad terms, that if farmers, researchers, funders, crop breeders, technology developers, and regulators, alike acknowledge incompleteness within their own knowledges and show willingness and seek opportunities to negotiate this knowledge through interactions with alternative (but similarly incomplete) knowledges, and if barriers to these interactions can be addressed, it will result in more appropriate and well-informed narratives of agricultural change.

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Appendix

Glossary of Terms

In science policy, complicated terms that are not part of everyday language often come to be used by different people to mean different things. WEMA maize, for example, is commonly described as 'biotechnology', 'transgenic', 'genetically engineered' and 'genetically modified' all of which may be used interchangeably, but may also be interpreted differently. For the sake of clarity, the glossary below gives the key terms used within this thesis and explains how the author wishes the reader to interpret them.

Biotechnology: a broad term that describes a product developed within, or with the use of, living organisms, the UN Convention on Biological Diversity (CBD) defines biotechnology as 'any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use'. The term therefore includes the modification of the genetic makeup of plants, but this includes cross-pollination, controlled breeding, mutagenesis (a process by which genetic mutation is induced), hybridization (the cross-pollination of trait-specific parents) and the direct extraction and insertion of genes from other organisms. Crop scientists will often make the point that biotechnology (e.g. making bread and cheese, or the purposeful breeding of plants and animals) has been in existence for thousands of years. **Modern biotechnology** is commonly used to specifically refer to genetic engineering (see below).

Genetic Engineering: the process of altering an organism's genome through the direct insertion of genetic material from elsewhere. There are a number of methods by which genetic material can be isolated (electrophoresis, enzyme splicing) and inserted (biolistically, bacterium-mediated).

Recombinant DNA: is a DNA sequence that includes genetic material from different species as a result of genetic engineering

Transgenic (or genetically engineered): describes an organism that has a DNA sequence containing a transgene (a gene or genetic material that has been transferred from elsewhere) inserted through genetic engineering.

Genetic Modification and Genetically Modified Organisms (GMOs): Although the description of biotechnology given above suggests that genetic modification could be inclusive of a whole spectrum of breeding techniques (note the use of the word 'modify' within the UN CBD definition of biotechnology) it is most commonly equated with genetic engineering. Preferably the terms would be avoided altogether to avoid confusion, but they are pervasive throughout literature and policies, so their use within this thesis is unavoidable. Unless otherwise stated, 'genetic modification' should be interpreted as being interchangeable with 'genetic engineering' and, likewise, 'genetically modified' should be read as 'transgenic'.

Methodology Appendix

Systematic Review of Climate-Crop Modelling Literature

The literature search was performed through two search engines: 'Science Direct' and 'Web of Knowledge'. A common search term was used to search in title, abstract, and key words' for Science Direct and 'topic' for Web of Knowledge (these are the equivalent search fields in the respective search engines. The search term was designed to capture all crop/climate model studies with at least a partial focus on maize agriculture in Kenya, published since 1992 (a further search term stipulation) and was follows: ('crop model*' OR 'climate model*') AND (Africa OR Kenya) AND (maize OR corn OR mays) AND (predict* OR projection OR simulation)

The search, conducted on 12/2/2012 produced a total of 65 results (18 from Science Direct and 47 from Web of Knowledge) of which 11 were duplicates and 9 of which could not be accessed, so the total number of reviewed publications was 45. Abbreviated references below:

- Hansen and Indeje (2004) Ag and Forestry Met 125(1): 143-157
- Hansen et al (2009) Ag Systems 101(1): 80-90
- Folberth et al (2012) Ag Systems 119(1): 22-34
- Tsubo et al (2007) J of Arid Env 71(3): 299-311
- Waha et al (2012) Glob Plan Change 106: 1-12
- Tittonell et al (2010) Eur J of Agron 32(1): 10-21
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- Gaiser et al (2010) Ag Systems 103(9): 656-665
- Jones et al (2003) Glob Env Change 13(1): 51-59
- Folberth et al (2012) Ag, Ecosys, Env 151: 21-33
- **Thornton et al (2009) Glob Env Change 19(1): 54-65**
- Lobell and Burke (2010) Ag and Forestry Met 150(1): 1443-1452
- Gaiser et al (2011) Ag and Forestry Met 151(8): 1120-1130
- **Thornton et al (2011) Phil Tran Royal Soc 369(1934): 117-136**
- Roudier et al (2011) Glob Env Change 21(3):1073-1083
- Tsubo et al (2005) Field Crop Res 93(1): 10-22
- Lourens and Jager (1997) Ag Systems 53(2): 303-315
- Kiniry et al (2002) Agron 22(3): 265-272
- Jones and Thornton (2002) Cons Ecol 5(2): 1-16
- Rowe et al (2006) Ag Ecos Env 116(1): 60-71
- Stige et al (2006) Proc Nat Ac Scientists Unit Stat 103(9): 3049-3053
- Nkomozepi and Chung (2012) Ag Wat Management 111: 60-67
- Lobell et al (2008) Science 319(5863): 607-610
- Knox et al (2012) Env Res Lett 7(3):1-8
- Sultan et al (2010) Weat, Clim, Soc 2(1): 69-87
- Gaiser et al (2010) Ag, Ecosys, Env 135(4): 318-327
- Ogola et al (2007) S African J Plant and Soil 24(1): 51-57
- Liu et al (2012) PLoS ONE 8(2): e57750
- Zinyengere et al (2011) Ag For Meteor 151(12): 1792-1799
- Dzotsi et al (2010) Ecol Mod 221(23): 2839-2849
- Berry and Clemence (1993) S. African J of Plant Soil 10(1): 1-5
- Haarhoff et al (1991) S. African J of Plant Soil 8(3): 158-160
- Crespo et al (2011) Clim Change 106(2): 267-283
- Tsubo and Walker (2007) J Arid Env 71(3): 299-311
- Singels et al (2010) Int Sugar J 114(1368): 894-898
- Gerardeaux et al (2012) Agron Sust Dev 33(3): 85-495
- **Tatsumi et al (2011) Hyd Proc 25(17): 2715-2725**
- Laux et al (2010) Ag For Met 150(9): 1258-1271
- Oguntunde and van de Giesen (2004) Int J Biometeor 49(2): 106-112
- Ines et al (2011) Int J Climatol 131(14): 2168-2182
- **Parry et al (2004) Glob Env Change 14(1): 53-67**
- Lourens and de Jager (1997) Ag Sys 53(2): 303-315
- Fader et al (2010) J Hydrol 384(3): 218-231
- Van Ittersum et al (2012) Field Crop Res 143: 4-17
- Reynolds et al (2000) Int J Remote Sens 21(18): 3487-3508

Of these 45 papers, four papers (in bold above), relating to three modelling projects, met the criteria of relating to the modelling of future maize yields in Kenya, East Africa, or Africa as a whole. Through a review of this literature further three projects, meeting the criteria, were also identified. The resulting six projects, which formed the basis of crop modelling production chain (Chapters Four and Five) are described in the following table:

1	**Parry et al.'s (2004)** nationally disaggregated global projections of yield trends for maize utilised outputs of the CERES-Maize model with input data from the HadCM2 climate model run under seven different emissions scenarios. They simulated crop growth at 124 sites in 18 countries (apparently 'representing major agricultural regions of the world' (Parry et al., 2004: 854), although none were in East or West Africa) and then extrapolated to regional levels on the basis of agroclimatic zone analysis. Maize yield in Kenya was shown to decline steadily in almost all emissions scenarios. It was repeated by **Iglesias and Rosenzweig (2009),** using the HadCM3 GCM.
2	**AVOID** – Avoiding dangerous climate change, a DECC/Defra funded research programme led by the UK Met Office, conducted a nationally disaggregated, global, multi-crop simulation exercise, using the climate projection outputs of 21 GCMs under two emissions scenarios (SRES A1B and 'an aggressive mitigation scenario' that sees a rapid decline in emissions after 2016), this was translated into a generic 'crop suitability index', and found that the total current cropland in Kenya is expected to experience increases in crop suitability could be anywhere from 0 to 75% under both emissions scenarios, and cropland experiencing a decrease in crop suitability could be anywhere from 0 to 80% under the A1B scenario and 0 to 70% under the mitigation scenario.
3	**Tatsumi et al. (2011)** used the Global Agro Ecological Zones (GAEZ) system to characterise agro-ecological conditions and compute potential crop yields for a number of crop types under 2090s climate conditions, as described by five GCMs driven by the SRES A1B emissions scenario. They projected a small (0.43) percentage increase in maize yield for Eastern Africa between a 1990-1999 mean and a 2090 projection
4	**Fischer (2009)**, used the GAEZ crops system, attempt to project 'potentially attainable rain-fed yield' changes by 2020s, 2050s and 2080s in the semi-arid tropics, running the model with a CO_2 fertilisation effect function both included and excluded. The GAEZ system was run under a set of 'optimal management practices and high inputs' (Fischer, 2009: 4) scenarios in order to calculate potential attainable yield. Climate input data came from two GCMs (CSIRO and HadCM3). The two climate models resulted in divergent trends for rain-fed maize yield potential in Eastern Africa
5	**Thornton et al.'s (2011)** used the average outputs of fourteen GCMs under three emissions scenarios and scaled anomalies within this output to a global temperature increase of +4°C, producing a picture of the climate at a resolution of 1°x1° (downscaled using the MarkSim programme) to calculate number of days in the year when moisture availability and temperature fall within generic crop growth thresholds. They project at 19% loss in maize yield for East Africa in a +4°C 2090 compared with the average for the 2000s. **Thornton et al.'s (2009)** paper present higher resolution data for East African crop projections generated through a combination of the CERES-Maize model with HadCM3 and ECHam4 GCM model outputs (with two IPCC scenario inputs: A1F1 and B1) – this shows high spatial variability in projected yield trends
6	**Nelson et al.'s (2009),** IFPRI IMPACT 2009 study combined the CERES-Maize model, run twice to both include and exclude the fertilisation effects of atmospheric CO_2, with climate outputs from two GCMs (CSIRO and NCAR), run under the A2 emissions scenario. Although they find that CO_2 effects mitigate some of the projected yield losses, they are not large enough to reverse an overall negative trend in global maize yields.

Primary Data Sources for Climate-Modelling Research

The following table details the data collected, analysed, and predominantly presented in Chapter Four on climate-crop modelling

Interviews	Location	Date	Code
Senior Climate Scientist (CSRP, UK Meteorological Office)	Exeter, UK	Jan 2012	CS1
Senior Climate Scientist (UK Meteorological Office)	Exeter, UK	Jan 2012	CS2
Earth System Modeller(UK Meteorological Office)	Exeter, UK	Jan 2012	CS3
Climate Scientist (UK Meteorological Office)	Exeter, UK	Jan 2012	CS4
Research Officer (UK Meteorological Office)	Exeter, UK	Jan 2012	CS5
Research Fellow (University of East Anglia)	Norwich, UK	Jan 2012	CS6
Research Fellow (University of Sussex)	Brighton, UK	Jan 2012	CS7
Research Fellow (Anonymous Affiliation, Crop Modelling specialism)	Brighton, UK	Feb 2012	CS8
Research Fellow (Anonymous Affiliation, Crop Modelling specialism)	Brighton, UK	Feb 2012	CS9
Professor (Anonymous Affiliation)	Brighton, UK	Feb 2012	CS10
Research Fellow (CGIAR, CCAFS)	Brighton, UK	Feb 2012	CS11
Senior Climate Scientist (Kenya Meteorological Department)	Nairobi, Kenya	Mar 2012	CS12
Research Scientist (WMO, Nairobi)	Nairobi, Kenya	Mar 2012	CS13
Senior Weather Forecaster (South African Weather Service)	Nairobi, Kenya	Mar 2012	CS14
Climate Research Scientist (IGAD Climate Prediction and Applications	Nairobi, Kenya	Mar 2012	CS15
Centre) Research Scientist (KARI Climate Change Unit)	Nairobi, Kenya	Jul 2012	CS16
Research Scientist (KARI, Climate Change Unit)	Nairobi, Kenya	Jul 2012	CS17
Research Theme Leader (CGIAR, CCAFS)	Nairobi, Kenya	Aug 2012	CS18
Email Correspondence			
Anonymous climate scientist		Jan 2012	CS19
Anonymous climate scientist		Jan 2012	CS20
Anonymous climate scientist		Jan 2012	CS21
Anonymous crop modeller		Jan 2012	CS22
Anonymous crop modeller		Jan 2012	CS23
Meeting/Workshop/Seminar Notes			
Hadley Centre Building Tour (UK Meteorological Office)	Exeter, UK	Jan 2012	FN1
Hadley Centre Seminar (UK Meteorological Office)	Exeter, UK	Jan 2012	FN2
Humanitarian Futures Programme Climate Exchange Workshop	Nairobi, Kenya	Mar 2012	FN3
CCAFS Seminar 'How good are current climate models at predicting agricultural impacts in Africa and South Asia?'	Nairobi, Kenya	Mar 2012	Sem1
CCAFS Web Seminar 'Managing droughts and floods for improved food security and livelihoods'	Web Seminar	Oct 2013	Sem2
Secondary Data			
CCAFS Crop Modelling for Climate Change and Food Security Survey		Dec 2010	CCSur

Primary Data Sources for Smallholder Farming Research

The following table provides information about data collected as part of research on smallholder maize farmers, which is mainly presented in Chapter Six.

Nyando/Nandi				Makueni			

Interviews*

30s Male + 30s Female [wife]	Kipkaren	Mar	N1	20s Male	Wote	June	M1
40s Male (+neighbour)	Kipkaren	Mar	N2	60s Female	Wote	June	M2
20s Male + 20s Female [wife] (+children)	Kipkaren	Mar	N3	20s Male	Wote	June	M3
60s Female	Kipkaren	Mar	N4	30s Male (+wife and children)	Wote	June	M4
60s Male + 60s Female [wife]	Kipkaren	Jul	N5	40s Female (+ children)	Wote	June	M5
60s Female + <20 Male [son]	Kipkaren	Jul	N6	40s Male	Kath'	June	M6
40s Male (+ children)	Ndalat	Jul	N7	40s Female + 40s Female [neighbour] + 40s Female [neighbour] (+ children)	Kath'	June	M7
30s Female	Ndalat	Jul	N8				
30s Female + 60s Female [mother] (+children)				20s Male	Kath'	June	M8
70s Male + 70s Female [wife]	Ndalat	Jul	N9	<20 Male	Kath'	June	M9
40s Female (+ children)	Ndalat	Jul	N10	60s Female + 30s Female [daughter in law]	Kath'	June	M10
30s Female (+ children)	Turbo	Jul	N11	50s Male	Wote	June	M11
40s Male (+wife and children)	Turbo	Jul	N12	40s Female + 40s Female [neighbour]	Wote	June	M12
40s Female + 40s Female [sister]	Turbo	Jul	M13	30s Male + 30s Male [neighbour]	Wote	June	M13
60s Female + 30s Male [son] + 30s Female [daughter in law]	Turbo	Jul	N14	80s Female (+children)	Wote	June	M14
				50s Male + 50s Female [wife] (+children)	Wote	June	M15
50s Male	Turbo	Jul	N15	60s Male	Wote	June	M16
<20 Male	Turbo	Jul	N16				
30s Male + 30s Male [neighbour]	Turbo	Jul	N17				
50s Female + 50s Female [neighbour]	Nyenyilel	Oct	N18				
50s Male + 50s Female [wife]	Nyenyilel	Oct	N19				
40s Male	Nyenyilel	Oct	N20				
60s Male	Nyenyilel	Oct	N21				
30s Female + 60s Female [mother] (+children)	Nyenyilel	Oct	N22				
40s Male							
60s Female + 60s Feale [neighbour]	Mutwot	Oct	N23				
60s Female + 30s Male [son] + 30s Female [daughter in law]	Mutwot	Oct	N24				
40s Female (+children)	Mutwot	Oct	N25				
30s Male + 30s Female [wife] (+children)	Mutwot	Oct	N26				
70s Male + 70s Female [wife] (+children)	Chebaiwa	Oct	N27				
50s Male + <20 Male [son]	Chebaiwa	Oct	N28				

Scenario Workshops

6 participants (4F, 2M)	Kipkaren	Oct	NW1	14 male participants	Wote	June	MW1
14 participants (4F, 10M)	Mutwot	Oct	NW2	18 female participants	Wote	June	MW2
12 participants (5F, 7M)	Nyenyilel	Oct	NW3				
30 participants (8F, 22M)	Ndalat	Oct	NW4				

Field Notes

Village walks	Mutwot	Oct	FNN1	Village walks	Ngosini	June	FNM1
	Ndalat	Oct	FNN2		Ngosini Dam	June	FNM2
	Nyeyilel	June	FNN3		Kyemole	June	FNM3
	Kipkaren	June	FNN4		Sende	June	FNM4
	Turbo	June	FNN5	Farm tours:			
Farm tours				2acre (maize)	Ngosini	June	FNM5
2acre (maize)	Mutwot (1)	Oct	FNN6	4acre (fruit)	Ngosini Dam	June	FNM6
2 acre (maize/beans)	Mutwot (2)	Oct	FNN7	5acre (mixed)	Kyemole	June	FNM7
4acre (maize)	Ndalat (1)	Oct	FNN8	2 acre (maize)	Sende	June	FNM8
1 acre (maize)	Ndalat (2)	Oct	FNN9				
5acre (maize, beans, veg)	Ndalat (3)	Oct	FNN10	Agricultural Show	Machakos	August	FNM9
8 acres (maize, sugar cane)	Nyeyilel	June	FNN11				
2 acre (maize, veg)	Kipkaren(1)	June	FNN12				
2acre (maize, beans, veg)	Kipkaren(2)	June	FNN13				
Tree nursery	Kipkaren (3)	June	FNN14				
2acre (maize, beans, veg)	Kipkaren (4)	June	FNN15				
10 acres (sugar cane)	Turbo (1)	June	FNN16				
1 acre (maize)	Turbo (2)	June	FNN17				
Agricultural Show	Eldoret (outside District)	Oct	FNN18				

Primary Data Sources for Smallholder Farming Research (cont.)

Nyando/Nandi				Makueni			
Climate Projections							
Rainfall projections for 2030 and 2050 using the CCAFS MarkSim tool with A1B emissions scenario input using ECHam5 (Lower Nyando)			**RainDataN**	Rainfall projections for 2030 and 2050 using the CCAFS MarkSim tool with A1B emissions scenario input using ECHam5 (Makindu)			**RainDataM**
Secondary Data							
CCAFS household (140 questionnaires) and village baseline survey data	Lower Nyando Basin	Mar	CCAFS.Sur.N	CCAFS household (140 questionnaires) and village baseline survey data	Wote	June	CCAFS.Sur.M
KMD monthly rainfall data	Kakamega Station**	2000-2011	KMD.N	KMD monthly rainfall data	Makindu Station	2000-2011	KMD.M

***** Information describes approx. age and gender of main respondent as well as details of other contributors [with relationship to main respondent in square brackets] and other non-contributing attendants (in brackets) /location/interview date/code

**The Kakamega weather station is the closest weather station to the Nyando/Nandi district

Analysis of Secondary Data – CCAFS Household Survey Data

The following figures are questionnaire pages from the CCAFS baseline household surveys conducted in Lower Nyando (Nyando/Nandi) and Wote (Makueni). 140 questionnaires were completed in each district. The information from these matrix questions about the changes in practice in crop farming and reasons for change were entered into a database and responses relating to maize farming (identified by a crop code specific to each district) were extracted. The questionnaire considers changes in farming practice and reasons for change separately, so in order to link changes in farming to associated reasons, one has to make assumptions. A simple statistical analysis was conducted in order to reveal the frequency of associated 'changes' and 'reasons' within responses. This is graphically displayed in Figure 14 of Chapter Six, which shows both frequency of responses for certain selected changes and the percentage of those responses that cited each reason (coded as relating to maize). Several of the changes were grouped (e.g. changes in land use and management options were grouped under one heading), for the purpose of presentation. It should also be noted that this frequency analysis indirectly suggests at associations, without information about statistical significance or robustness. Because the data provides preliminary information, which is later tested and triangulated through primary qualitative data, and because of the significant sources of error in the data that come from the nature of the questionnaire (i.e. these matrices are filled out on the basis of open ended questions about recent changes on the farm), these frequency analyses provide an appropriate level of information for the purposes of the research.

CCAFS Baseline Household Level Questionnaire

Site ID (SITEID)				
Block ID (BLOCKID)				
Village ID (VILLID)				
Household ID (HHID)				

Section IV: - Crop, Farm Animals/Fish, Tree and SLM Changes

Read the following question as an introduction to the questioning.

1. I would now like you to tell me what changes you have made in the way you have been managing your land, crops and farm animals over the last 10 years.
[If the respondent is obviously too young to have been farming over the last 10 years, ask about what their father did over the last 10 years at this location]

1. Have you or your family been farming or keeping animals or fish in this locality for 10 years or more? *(01=Yes, 00=No)*	FARM10YR	[___]

2. Now I would like to hear about changes you have made in the types of crops you have grown within the last 10 years

Have you …		Write the crop codes (use the code sheet)			
		CRP1	CRP2	CRP3	CRP4
Introduced any new crop?(over some time) *(see crop codes)*	CRIN	[___]	[___]	[___]	[___]
Are you testing any new crop (still not sure about) *(see crop codes)*	CRTS	[___]	[___]	[___]	[___]
Stopped growing a crop (totally) *(see crop codes)*	SGCT	[___]	[___]	[___]	[___]
Stopped growing a crop (in one season) *(see crop codes)*	SGC1	[___]	[___]	[___]	[___]

3. What are your three most important crops? By 'main crop' I mean the crops you grow on your farm which are most important to your household's livelihood. *(see crop codes)*	MNCRPNW1	[___]
	MNCRPNW2	[___]
	MNCRPNW3	[___]
4. What were your three most important crops 10 years ago? *(see crop codes)*	MNCRP101	[___]
	MNCRP102	[___]
	MNCRP103	[___]
5. What are your three most important farm animals or fish? By 'main farm animals' I mean the animals you keep on your farm which are most important to your household's livelihood. *(see farm animal and fish codes)*	MNFRMNW1	[___]
	MNFRMNW2	[___]
	MNFRMNW3	[___]
6. What were your three most important farm animals or fish 10 years ago? *(see farm animal and fish codes)*	MNFRM101	[___]
	MNFRM102	[___]
	MNFRM103	[___]

CCAFS Baseline Household Level Questionnaire

Site ID (SITEID)
Block ID (BLOCKID)
Village ID (VILLID)
Household ID (HHID)

Read the following question as an introduction to the questioning.

7a. Tell me more about what changes you have made to the crop varieties you have planted over the last 10 years ....

Ask the respondent to tell a story and take notes on a separate page, fill in the table after the interview, before you leave the household in case follow up is needed.

Have you/Are you...		Crop code CRP1	Crop code CRP2	Crop code CRP3	Crop code CRP4	Crop code CRP5
Introduced new variety of crops	NWVR	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Planting higher yielding variety	PHYV	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Planting better quality variety	PBQV	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Planting pre-treated/improved seed	PPIS	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Planting shorter cycle variety	SHCY	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Planting longer cycle variety	LGCY	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Planting drought tolerant variety	DRTL	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Planting flood tolerant variety	FDTL	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Planting salinity-tolerant variety	SLTL	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Planting toxicity-tolerant variety	TXTL	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Planting disease-resistant variety	DSTL	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Planting pest-resistant variety	PSRS	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Testing a new variety	NVTS	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Stopped using a variety	STVR	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]
Other, specify (SPECCHCP) 7a.________________	OTHS	[___ ___]	[___ ___]	[___ ___]	[___ ___]	[___ ___]

CCAFS Baseline Household Level Questionnaire

Site ID (SITEID)
Block ID (BLOCKID)
Village ID (VILLID)
Household ID (HHID)

7b. Tell me more about what changes you have made in the way you manage your land, soil and water and in how you have prepared your land over the last 10 years, and which crops these changes affected.

Make sure you prompt for fruit, vegetables, cash crops, fodder and tree crops.

Ask the respondent to tell a story and take notes on a separate page, fill in the table after the interview, before you leave the household in case follow up is needed.

Land Use and management		Crop code CRP1	Crop code CRP2	Crop code CRP3	Crop code CRP4	Crop code CRP5
Expanded area	EXAR	[__ __]	[____]	[__ __]	[____]	[__ __]
Reduced area	RDAR	[__ __]	[____]	[__ __]	[____]	[__ __]
Started irrigating	STIR	[__ __]	[____]	[__ __]	[____]	[__ __]
Stopped irrigating	SPIR	[__ __]	[____]	[__ __]	[____]	[__ __]
Stopped burning	SPBR	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced intercropping	INCR	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced crop cover	CRCV	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced micro-catchments	MCCT	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced/built ridges or bunds	BUND	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced mulching	MULC	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced terraces	TERR	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced stone lines	STLN	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced hedges	HEGD	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced contour ploughing	CTPL	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced rotations	ROTA	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced improved irrigation (water efficiency)	INIR	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced improved drainage	INID	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced tidal water control management	INWC	[__ __]	[____]	[__ __]	[____]	[__ __]
Introduced mechanized farming	INMF	[__ __]	[____]	[__ __]	[____]	[__ __]
Earlier land preparation	ELPP	[__ __]	[____]	[__ __]	[____]	[__ __]
Earlier planting	ELPT	[__ __]	[____]	[__ __]	[____]	[__ __]
Later planting	LTPT	[__ __]	[____]	[__ __]	[____]	[__ __]
Started using or using more mineral/chemical fertilisers	MNFT	[__ __]	[____]	[__ __]	[____]	[__ __]
Started using manure/compost	MNCP	[__ __]	[____]	[__ __]	[____]	[__ __]

Data Sources for DTMA and WEMA Research

The following table lists sources of information analysed in the initial review of the DTMA and WEMA projects (all material was accessed from the DTMA and WEMA websites between December 2011 and February 2012). This material formed the basis of the initial project maps (Chapter Four).

Information Type	Material	
	DTMA	WEMA
Project Overview Documents		• WEMA Concept Note • WEMA Project Brief
Plenary Meeting Notes	• 2008 Annual Planning Meeting (short description) • 2009 Annual Planning Meeting (short description)	
Project Reports	• Community Assessment of Drought Tolerant Maize for Africa (DTMA) in Kenya (2009) • Characterization of Maize Producing Households in Machakos and Makueni Districts in Kenya (March 2010) • Results of the 2008 Regional Maize Trials Coordinated by CIMMYT-Kenya • Results of the 2009 Regional Maize Trials Coordinated by CIMMYT-Kenya • Results of the 2010 Regional Maize Trials Coordinated by CIMMYT-Kenya	• WEMA Progress Report (March 2008-March 2011) • 2012 WEMA Progress Update • WEMA Project Report (May 2012)
Policy Documents		• WEMA Intellectual Property Policy • Project Collaboration and Intellectual Property Agreement • Project Policy on Regulatory Approvals
Policy Briefs	• 'Five years on Addressing the Needs of Smallholder Farmers in Africa' (no date)	• 'Reducing maize insecurity in Kenya: the WEMA project (November 2010) • 'The Role of Biotechnology in mitigating impacts of drought on maize production in Kenya' • 'Mitigating the impact of drought in Tanzania: the WEMA intervention' • 'Facts on the safety of modern biotechnology' • 'Enhancing maize productivity in Uganda through the WEMA project' • 'Rationale for a biosafety law for Uganda' • 'The disparity between South Africa's biotechnology policy legislation'
Methods and Evaluation	• The DTMA Field Book (2008) • Geographic Information Systems Module	
Website statements	• Project Background • DTMA Project Definitions • Frequently Asked Questions	• Project Outline • Project Objectives • 'The Problem' • Frequently Asked Questions • 'Timelines and Milestones'
Social Audit Report Documents		• Social Audit Reports (2009, 2010, 2011) • Management Response to Social Audit Reports (2009, 2010, 2011)
Press releases	• 'No maize, no life!' (November 2011) • 'Maize without borders: Reforming maize seed sector policies to meet farmers' needs in Africa' (2011) • 'Doubled haploids seed development of drought tolerant maize for Africa' (no date) • 'DT maize will greatly profit African farmers' (15 April 2010)	• Scientists Prepare for Confined Field Trials of Life-Saving Drought-Tolerant Transgenic Maize (14 October 2010) • AATF Marks Second Anniversary Since Formation of WEMA Project (no date)

Interviews were conducted with people in the following roles in connection with the WEMA project; details of the interview and the assigned code used for reference in the thesis are included:

Participant			Code
Crop Breeder (CIMMYT)	Nairobi, Kenya	Mar 2012	DW1
Crop Breeder (CIMMYT)	Nairobi, Kenya	Jun 2012	DW2
Crop Breeder (CIMMYT)	Nairobi, Kenya	Aug 2012	DW3
Crop Breeder (CIMMYT)	Makindu, Kenya	Jun 2012	DW4
Trial Site Manager (CIMMYT)	Makindu Kenya	Jun 2012	DW5
Trial Site Manager (CIMMYT)	Makindu, Kenya	Jun 2012	DW6
Social Science Research Fellow (CIMMYT)	Nairobi, Kenya	Apr 2012	DW7
Project Manager (AATF)	Nairobi, Kenya	Nov 2012	DW8
Seed Systems Coordinator (AATF)	Nairobi, Kenya	Mar 2012	DW9
Regulatory Systems Manager (AATF)	Nairobi, Kenya	Aug 2012	DW10
Communications Manager (Monsanto, Kenya)	Nairobi, Kenya	Aug 2012	DW11
Crop Scientist (KARI)	Nairobi, Kenya	Apr 2012	DW12
Crop Scientist (KARI)	Nairobi, Kenya	Apr 2012	DW13
Crop Scientist (KARI)	Nairobi, Kenya	Aug 2012	DW14
Climate Change Unit Representative (KARI)	Nairobi, Kenya	Aug 2012	DW15
Anonymous Respondent	Nairobi, Kenya	Mar 2012	DW16
Anonymous Respondent	Nairobi, Kenya	Apr 2012	DW17
Anonymous Respondent	Nairobi, Kenya	Apr 2012	DW18
Anonymous Respondent	Nairobi, Kenya	Jun 2012	DW19
Centre Director (ISAAA Afri-Centre)	Nairobi, Kenya	Jun 2012	DW20

Data Sources for Biosafety Regulation Research

An initial review of policy processes around the establishment and implementation of the Kenyan Biosafety Act was based on the following key peer-reviewed and grey literature:

- Harsh, M. (2005). 'Formal and informal governance of agricultural biotechnology in Kenya: participation and accountability in controversy surrounding the draft biosafety bill.' Journal of International Development 17(5): 661-677.
- Harsh, M. and J. Smith (2007). 'Technology, governance and place: Situating biotechnology in Kenya.' Science and Public Policy 34(4): 251-260.
- Jaffe, G. (2006). Comparative analysis of the national biosafety regulatory systems in East Africa, Free downloads from IFPRI.
- Kamanga, D. (2008). 'East Africa pushes GM law.' Nature Biotechnology 26(11): 1209-1209.
- Kameri-Mbote, P. (2002). 'The development of biosafety regulation in Africa in the context of the Cartagena Protocol: Legal and Administrative Issues.' Review of European Community & International Environmental Law 11(1): 62-73.
- Karembu, M., et al. (2010). Developing a biosafety law: lessons from the Kenyan experience. Nairobi, ISAAA AfriCentre.
- Kimani, V. and G. Gruère (2010). 'Implications of import regulations and information requirements under the Cartagena Protocol on Biosafety for GM commodities in Kenya.'
- Kingiri, A. and S. Ayele (2009). 'Towards a smart biosafety regulation: The case of Kenya.' Environmental Biosafety Research 8(03): 133-139.
- Kingiri, A. N. (2010). 'Experts to the rescue? An analysis of the role of experts in biotechnology regulation in Kenya.' Journal of International Development 22(3): 325-340.
- Kingiri, A. N. (2011). 'Conflicting advocacy coalitions in an evolving modern biotechnology regulatory subsystem: policy learning and influencing Kenya's regulatory policy process.' Science and Public Policy 38(3): 199-211.
- Kleinman, D. L., et al. (2009). 'Local variation or global convergence in agricultural biotechnology policy? A comparative analysis.' Science and Public Policy 36(5): 361-371.
- Traynor, P. L. and H. K. Macharia (2003). Analysis of the biosafety system for biotechnology in Kenya: Application of a conceptual framework, ISNAR.
- Wafula, D., et al. (2011). The RABESA Project 2004-2011: Achievements and Future Prospects. International Service for the Acquisition of Agri-biotech Applications and Program of Biosafety Systems.
- Wafula, D., et al. (2007). Applying Biotechnology in a safe and Responsible manner: Justification for a Biosafety Law in Kenya, International Food Policy Research Institute (IFPRI).

The following table provides information about primary and secondary data collected and analysed as part of research on Kenyan biosafety regulation, which is mainly presented in Chapter Eight.

Interviews	Location	Date	Code
NBA Research Officer	Nairobi, Kenya	April 2012	BS1
NBA Chief Executive Officer	Nairobi, Kenya	April 2012	BS2
Director ABSF	Nairobi, Kenya	April 2012	BS3
Representative of the Kenyan Ministry of Agriculture	Nairobi, Kenya	May 2012	BS4
Centre Director (ISAAA Afri-Centre)	Nairobi, Kenya	May 2012	BS5
AATF Regulatory Team Member	Nairobi, Kenya	Jul 2012	BS6
Representative of the Cereal Millers Association	Nairobi, Kenya	Aug 2012	BS7
NBA Communications Officer	Nairobi, Kenya	Aug 2012	BS8
NBA Director of Technical Services	Nairobi, Kenya	Aug 2012	BS9
Representative of KOAN	Nairobi, Kenya	Aug 2012	BS10
Research Fellow – African Centre for Technology Studies	Nairobi, Kenya	Oct 2012	BS11
Representative of Kenyan Biodiversity Coalition	Nairobi, Kenya	Oct 2012	BS12
KARI Institutional Biosafety Committee Member	Nairobi, Kenya	Nov 2012	BS13
AATF Regulatory Team Member (2)	Nairobi, Kenya	Nov 2012	BS14
Anonymous	Nairobi, Kenya	Nov 2012	BS15
Meeting/Workshop Notes			
OFAB Meeting (Food Standards and GMO Labelling)	Nairobi, Kenya	May 2012	OF1
OFAB Meeting (GMO Labelling and Lethal Maize Necrosis)	Nairobi, Kenya	June 2012	OF2
OFAB Meeting (Cereal Millers Association)	Nairobi, Kenya	Jul 2012	OF3
Annual National Biosafety Conference	Nairobi, Kenya	Aug 2012	ANBC
OFAB Meeting (Implications of the ban on GMO importation)	Nairobi, Kenya	Nov 2012	OF4
Secondary Data			
WEMA application for the importation of GM material	NBA Head Office		WAp1
WEMA application for the establishment of a confined field trial	NBA Head Office		WAp2
OFAB Meeting Minutes (2006-2012)			
Newspaper Articles:			

Daily Nation:
Ban on genetic foods is illegal, claim MPs (15/7/13)
Legal status of GMO probe team queried (20/5/13)
Ban on GM foods was political, says Kiome (1/5/13)
GM food not approved for sale, says regulator (25/11/12)
GMOs ban to hit relief food efforts (22/11/12)
Cabinet would do well to avoid scare-mongering over GMOs (13/11/12)
Don't dismiss new findings on GMOs (7/10/12)
Approved GM products are not on sale, says authority (30/8/12)
Can we do without GMO technology? (28/8/11)
Agency 'lacks power to vet GM imports' (12/8/11)
Scholars in bid to put GM food fears to rest (10/8/11)
Kenya imported GMO maize, House told (3/8/11)
Publishing rules on GMO imports starts (18/7/11)
Leave debate on GM foods (18/7/11)
What Moi thought of GMOs 11 years ago (18/7/11)
Cabinet clears GM maize imports (14/7/11)
Kenya approves import of GMO maize (14/7/11)
Minister denies GM maize imports cleared (13/7/11)
The shocking reality about GMOs (11/7/11)
Hunger crisis rekindles debate over GM maize (2/7/11)
150 states back Kenya on GMOs (12/10/10)
GMO law to go live (23/6/10)
Move to shield Kenyans from GM maize (25/4/10)
Kenya 'aware that maize was GMO' (19/4/10)
Tough rules set to govern GMOs (14/3/09)
GMOs given legal backing (23/2/09)
Biosafety law required (9/10/08)
Comesa joins in GMO debate (17/9/08)
Court rejects bid to stop GMO debate (12/10/07)
Genetically modified foods debate passes first hurdle (12/10/07)
13 in court to block Bill on GM (10/10/07)
Biosafety Bill too rushed (5/10/07)
Members support Bill on GMO food (5/10/07)
Enact biosafety laws promptly (18/7/06)
Intrigues behind Biosafety Bill (4/5/06)

The Star:
National Biosafety Authority to ensure gmo foods safety (6/5/13)
Label GMO foods activists demand (17/10/12)
NGOs plot to block new GMO laws (24/8/11)
Labelling guidelines to be developed for GMOs (23/8/11)
Kamar calls for public education on GMOs (9/8/12)
Commerce behind push for GMOs, PS now claims (27/7/11)
Health ministry pushes for labelling of GMO foods (14/7/11)
GMO maize regulations gazetted (5/6/11)
Kenya poised to adopt GMO to boost yields (13/4/11)

Coding Words

Analysis of field notes, interview transcripts and policy and project documents was achieved through manual coding and classification of key words and phrases that perform one or more of the following functions:

- Indicates a gap in knowledge, methodological choice, or assumption.
- Helps to characterise and categorise incomplete knowledge (i.e. as uncertainty, ignorance, ambiguity, risk).
- Represents an interpretation of evidence or a denial of the incompleteness of knowledge.
- Represents the attachment of a meaning or a real world interpretation based on (incomplete) knowledge/evidence.
- Indicates the origins, motivations or explanations for attaching this meaning or interpretation.
- Represents a mechanism of inclusion or exclusion in knowledge exchange (structural, communicative, and cognitive) or a barrier to participation (trust, culture).
- Identifies the aims or outcomes a particular knowledge exchange (best argument, opening up to and maintaining multiple pathways, learning, narrative change).

The following code words were used in analysing the textual data (interview transcripts, field notes, secondary data sources, etc.) in this research.

Knowledge Gap	Incomplete Knowledge	Evidence	Narrative	Origins	Mechanisms of Inclusion/Exclusion	Aims of Exchange
• Assumption • Estimation • Guess • Probabilistic judgement • Methodological Choice • Value Judgement • Indicators • Preference • Priority	• Risk • Uncertainty • Ambiguity • Ignorance	• Evidence-based policy • Qualifying statistics (national/global) • Performance indicators • Safety indicators • Closing down	• Characters (stakeholders) • Settings • Plotline • Exclusions	• Politics • Financial Interest • Traditions • Trust/distrust • Innovation • Experiential • Negative • Positive	• Structural • Communicative • Cognitive • Trust • Culture • Social learning	• Best argument • Persuasion • Sensitization • Opening up to/ maintaining multiple pathways • Learning • Narrative change • Policy